BIODIVERSITY, CLIMATE CHANGE AND LIVELIHOODS: A STUDY ON ECONMOIC AND ECOLOGICAL SUSTAINABILITY AMONG COFFEE PRODUCERS IN THE HIGHLANDS OF NICARAGUA

By

Aniseh Sjona Bro

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Community Sustainability – Doctor of Philosophy

2016

ABSTRACT

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Efforts to slow down and eventually reverse the trend of climate change will take time, and in some cases, its negative impacts will be felt long before long-term solutions to this problem can bear fruit. Adaptation and mitigation strategies constitute the front line of attack for rural households in low-income countries that rely on agricultural production and natural resource use as their main sources of income and growth, and whose livelihoods are threatened by climate change.

Coffee in Nicaragua is the main source of income for thousands of smallholder producers, and is the country's primary agricultural export. Given the vulnerability of coffee to the impacts of climate change there is a growing consensus among development practitioners and policy makers that adaptation strategies are necessary and in some cases urgent for those producers who depend on coffee production as their main source of income.

In this dissertation, comprised of three empirical papers, I study the coffee sector in the Matagalpa region of Nicaragua and explore potential pathways for climate change adaptation among its coffee producers by studying their options for building adaptive capacity and the necessary conditions to help them adopt technologies and practices that promote successful adaptation.

The focus of the first paper is on the characteristics of coffee producers in northern Nicaragua and their capacities for climate change adaptation and vulnerabilities its shocks,

including an exploration of their attitudes towards risk through the use of experimental risk games. An important finding from this study is that household food insecurity is a key determinant of risk aversion, and that income is relevant insofar as it results in greater food security.

In the second paper, I use choice experiments to elicit farmers' preferences for shade incorporation into coffee farms. Shade is an important farm management practice in coffee production because it helps to protect soils, promote biodiversity, and helps to mitigate the impacts of higher temperatures induced by climate change. I find that for a small premium farmers are willing to incorporate additional shade into their farms. An unexpected finding from this study is that farmers are not willing to give up any coffee income to have access to pesticides for their farms, a likely reflection of the recent leaf rust outbreak in the country and the poor institutional response to the outbreak.

Finally, I analyze the degree to which cooperatives can help farmers adopt a set of ten production practices that can help farmers build adaptive capacity to climate change. Results show that coffee farmers who belong to cooperatives have already adopted these practices at higher rates than non-members, and econometric analyses confirm this result. A factor analysis is also conducted to determine the underlying structural differences among the ten practices, and from this analysis three factors emerged and are modeled. Cooperative membership emerges as a significant determinant of adoption of practices that promote water conservation.

To my mom and dad. Mis dos pilares.
To Jason. My love.

ACKNOWLEDGEMENTS

This work would have not been possible without the support, both academic and personal, that my advisor and mentor, Dr. Daniel Clay, has given me during these past years. Dan has taught me the value that good mentorship can bring to a relationship, from helping me with my professional and academic development to giving me instructions on how to build a bench for my dining room; from giving me the opportunity to be closely involved in his projects, while encouraging me to pursue my personal research interests. Dan, working with you and learning from you has truly been the highlight of my tenure as a PhD student, and I hope to someday be as good a mentor to others, as you have been to me.

I would also like to thank my advisory committee: Dr. Maria Claudia Lopez, thank you for helping me stay focused on the long term goals, and for allowing me to go to you whenever I felt too overwhelmed with the task ahead. Dr. Robert Richardson, thank you for pushing me to think more critically about my work and for all of your encouragement and advise through the years. Dr. David Ortega, thank you for the countless hours that you dedicated to helping me with the research; the time that you dedicated to teaching me new methods has been invaluable.

The friendships forged at Michigan State University have made this journey an adventure that I would gladly take again, being away from home often means looking outside our blood relations to get the companionship and support that we all need when we are far, and I trust that the friendships that I have made here will last through the years.

My mom, dad, brother, sister, and nephews accompanied me and kept me motivated in the distance, and I thought of them every day.

Finally, I have to thank my husband, Jason Snyder, without whom I do not know how all of this would have been possible. Thank you for encouraging me to push myself and to pursue my dreams, for the many hours that you spent proofreading my papers, for hugging me when it all felt like too much, for never doubting in me, and for never losing your sense of humor that helped me navigate this PhD labyrinth. I love you. Every day.

I would also like to acknowledge the financial support of the United States Agency for International Development through the Borlaug Fellows in Global Food Security at Purdue University, the support of the Graduate School at Michigan State University through its Dissertation Completion Fellowship, and the financial support of the Department of Community Sustainability at Michigan State University.

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KEY TO ABBREVIATIONS

DCE	Discreet Choice Experiments
CIAT	International Center for Tropical Agriculture
RPL	Random Parameter Logit
WTC	Willingness to Change
WTP	Willingness to Pay
IPCC	Intergovernmental Panel on Climate Change
SLM	Sustainable Land Management

Chapter 1: Introduction

"Let us not, however, flatter ourselves overmuch on account of our human conquest over nature. For each such conquest takes its revenge on us. Each of them, it is true, has in the first place the consequences on which we counted, but in the second and third places it has quite different, unforeseen effects which only too often cancel out the first. The people who, in Mesopotamia, Greece, Asia Minor, and elsewhere, destroyed the forests to obtain cultivable land, never dreamed that they were laying the basis for the present devastated condition of these countries, by removing along with the forests the collecting centres and reservoirs of moisture. When, on the southern slopes of the mountains, the Italians of the Alps used up the pine forests so carefully cherished on the northern slopes, they had no inkling that by doing so they were cutting at the roots of the dairy industry in their region; they had still less inkling that they were thereby depriving their mountain springs of water for the greater part of the year, with the effect that these would be able to pour still more furious flood torrents on the plains during the rainy seasons. Those who spread the potato in Europe were not aware that they were at the same time spreading the disease of scrofula. Thus at every step we are reminded that we by no means rule over nature like a conqueror over a foreign people, like someone standing outside nature—but that we, with flesh, blood, and brain, belong to nature, and exist in its midst, and that all our mastery of it consists in the fact that we have the advantage over all other beings of being able to know and correctly apply its laws."

Frederick Engels, 1883

Human influence on the climate system, driven by economic and population growth, is clear, and has caused global greenhouse gas emissions to reach the highest levels in recorded history. As a result, these changes have had a significant impact on human and natural systems. Water resources have been affected by changes in precipitation and to melting snow and ice. Some studies have found a shift in crop suitability[1] in many regions of the world (Laderach et al., 2011; Fischer et al., 2002). At this rate, the planet will see long-lasting changes in all components of the climate system, and the likelihood of severe and irreversible impacts on people and ecosystems will increase. The latest IPCC report paints a dark future for our planet. The authors state that "it is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases. It is very likely that heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur" (IPCC, 2014).

Climate change impacts will be felt worldwide, yet the scale and intensity of these impacts will differ by region. Urban areas will experience a loss of assets, increased air pollution, and water scarcity, while rural areas will be at greater risk of food insecurity, changes in agricultural incomes, and shifts in production areas for food and non-food crops. Displacement of people will occur in both sectors, rural and urban, with poor households being affected disproportionately.

[1] Crop suitability refers to the agro-ecological suitability of a region for the production of particular crops or types of crops.

The IPCC (2014) states that for the world population to adapt to climate change, effective decision-making and policy implementation are necessary and that they should be informed by a range of analytical approaches that evaluate the risks and benefits of interventions, while considering the significance of institutions, equity, economic implications, and the diverse perceptions and response to risk and uncertainty.

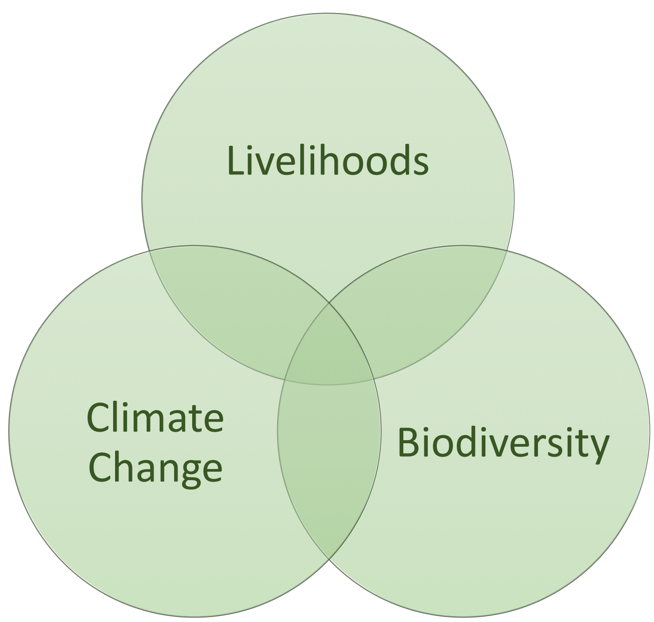
Nicaragua is one of the poorest countries in Latin America with more than 42% of the population living under the poverty line and most in rural areas (World Bank, 2016). Coffee in Nicaragua is by far the most important crop in the economy, and is its highest source of agricultural export revenues. There are more than 48,000 coffee producers in Nicaragua, producing mostly Arabica coffee, and the majority of them farm on plots of less than 3.5 hectares (Valkila and Nygreen, 2010).

Climate change is expected to affect a large proportion of coffee growing areas in Nicaragua. Overall, the climate will be marked by greater seasonality in terms of the variability in temperatures and precipitation. Areas of Nicaragua, including Matagalpa-- where this research takes place-- will see a loss in agro-ecological suitability for coffee of up to 60% due to climate change (Laderach et al., 2011).

Efforts to slow down and eventually reverse the trend of climate change will take time, and in some cases, the negative impacts of climate change will be felt long before long-term solutions to this problem can take hold. Adaptation and mitigation strategies for rural households constitute the front line of attack for rural households in developing countries that rely on agricultural production and natural resources use as their main source of income and growth, and whose livelihoods are threatened by climate change. Among these strategies, the adoption of sustainable and "climate smart" production practices has been identified as critical for smallholder producers, but it is uncertain how best they should be promoted (Laderach *et al.*, 2013).

The research presented in the following chapters explores the implications of climate change on the livelihoods of coffee producers in Nicaragua. It examines the pathways to climate change resilience for coffee producers in the region along three main dimensions: livelihoods, biodiversity conservation, and climate change adaptation (Figure 1).

Figure 1. Research Conceptual Framework



Throughout this dissertation I make use of the terms *resilience* and *adaptive capacity* on numerous occasions. For purposes of this research, I define adaptive capacity as the capacity of coffee producers in Matagalpa to adopt technologies and practices that help them become more resilient to climate change, while resiliency is defined as the capacity of coffee farmers to recover from climate change shocks and minimize the losses.

This dissertation is divided into three main empirical chapters, each one meant to stand on its own as a publishable manuscript. It is for this reason that sections presenting a description of the data and the study appear partially repetitive across the three empirical chapters.

Chapter 2, *Climate Change Adaptation, Food Security and Attitudes Toward Risk among Smallholder Coffee Farmers in Nicaragua*, paints a broad picture of the coffee sector in the region, and it explores the incentives and the capacities of coffee producers in Nicaragua to adopt technologies that will help them be resilient to climate change. Adaptation to climate change is essential for poor rural households that choose to make a living from coffee production, and the strategies that they can adopt are multiple. I explore these questions through the use of descriptive analyses and experimental economic methods. I find that producers in the region have already experienced environmental shocks and have had to respond to some of these shocks through various coping mechanisms, some of which leave them even more vulnerable to future shocks. I also explore coffee farmer attitudes towards risk by analyzing data from lottery games with real pay-offs that were implemented in the field. This study helps us understand the options for building adaptive capacity and the vulnerabilities to climate change experienced by coffee farmers; an important first step in exploring the best way to help the sector become more resilient to the impacts of climate change.

Chapter 3, *Adaptive Capacity to Climate Change: Coffee Farmers' Preferences for Crop Diversification in Nicaragua*, is focused on the conditions under which coffee producers diversify their coffee production with additional shade crops to help protect the biodiversity of the regions where coffee is produced. Shade incorporation into coffee fields is important because it promotes biodiversity conservation, it helps with climate change adaptation by lowering the temperatures of fields and by protecting the soils, and it has the potential to generate income and food for consumption. I employ choice experiments to elicit farmers' willingness to change their production practices to include shade in their coffee farms. In a choice experiment, respondents are asked to choose between bundles containing a series of different attributes (of varying levels) from hypothetical choice scenarios. By controlling the variation in the levels of the attributes, I am able to analyze the choices made by the respondents and to estimate marginal values for the attributes presented in the choice sets. Results from this paper highlight how some of the institutional responses to the leaf rust epidemic in Nicaragua have affected the preferences of farmers and I discuss its impacts on the level of trust that farmers have in the ability of organizations to provide help under stressful conditions.

Chapter 4, *Determinants of Adoptions of Sustainable Production Practices among Smallholder Coffee Producers in Nicaragua*, models the determinants of adoption of ten different production practices that can help producers become more resilient to climate change. I explore the extent to which farmer cooperatives affect the adoption of improved production practices and I create an indicator for these ten practices and explore the degree to which membership affects adoption. Not all technologies are equal, some may be more important than others, so a factor analysis was conducted to determine the underlying structural differences among the ten practices, and from this analysis three factors emerged and were modeled, to measure the degree to which membership affects adoption of each set of practices. Results from this study help inform more efficient and effective pathways to help farmers to adopt practices that aid them in building adaptive capacity to climate change.

The goal of this dissertation is to generate findings that are valuable for policy makers, donors as well as development and extension practitioners in the coffee sector as they endeavor to forge future courses of action and guide policy toward more effective solutions.

REFERENCES

REFERENCES

Engels, Friedrich. Engel, F. Dialectics of Nature. (1883).

Fischer, Günther, Mahendra Shah, and Harrij Van Velthuizen. "Climate change and agricultural vulnerability." (2002).

Intergovernmental Panel on Climate Change. *Climate change 2014: mitigation of climate change*. Vol. 3. Cambridge University Press, 2015.

Laderäch, Peter, et al. "Predicted impact of climate change on coffee supply chains." The Economic, Social and Political Elements of Climate Change. Springer Berlin Heidelberg, 2011. 703-723.

Laderäch, Peter, Carlos Zelaya, Oriana Ovalle, Samuel Garcia, Anton Eitzinger, and Maria Baca. "Escenarios del Impacto del Clima Futuro en Areas de Cultivo de Cafe en Nicaragua." CIAT Blog. 13 Mar. 2013. Web. http://dapa.ciat.cgiar.org/wp-content/uploads/2012/03/Informe-Nicaragua-final.pdf

Valkila, Joni, and Anja Nygren. "Impacts of Fair Trade certification on coffee farmers, cooperatives, and laborers in Nicaragua." *Agriculture and Human Values* 27.3 (2010): 321-333.

World Bank. (2016) Retrieved from http://data.worldbank.org/data-catalog/gdp-ppp-based-table

Chapter 2: Climate Change Adaptation, Food Security and Attitudes Toward Risk among Smallholder Coffee Farmers in Nicaragua

Introduction

The earth's climate is changing rapidly. Climate scientists forecast higher temperatures and significant changes in precipitation patterns, that in turn will alter crop suitability and land use in many agricultural regions of the world (IPCC, 2014). Farmers will see changes in their agricultural productivity, their farm income, and their food security (Laderach et al., 2011). Poor, rural households in developing countries that depend directly on natural resources for income generation and their own food consumption will be burdened disproportionately by the adverse impacts of climate change; because their livelihoods are so closely tied to the local agroecology they will be among the most vulnerable to sudden shocks like droughts, floods, famine, fires, epidemics, and potentially violent conflict (Ellis, 2000). For farmers, especially vulnerable smallholder farmers, the adoption of new practices and technologies that help them become more resilient to these changes will be one of the most important paths for protecting their livelihoods. Their willingness to adopt these improved practices and technologies, their level of risk tolerance, and the institutional response mechanisms will go a long way in determining their success in adapting to these changes.

Policy makers, non-governmental organizations (NGOs), and other organizations, but especially vulnerable smallholder farmers, will need to understand how their livelihoods will be impacted by climate change and must take the necessary actions towards increased resiliency. Stakeholders in the agricultural sector will need to provide vulnerable farmers with the support needed to transition toward more resilient livelihoods. Among those most vulnerable to the impacts of climate change are women and the elderly, so adaptation strategies must incorporate equitable coping mechanisms that will enhance resiliency even among the most disadvantaged groups (Tompkins and Adger, 2004). For the purposes of this research I draw on the IPCC (2001) definition of vulnerability, which hinges on the sensitivity of agriculture to changes in climate, the adaptive capacity of the ecosystem, and the degree of exposure to climate hazards.

Smallholder farmers' attitudes and incentives towards new technology adoption or alternative production practices have long been documented in the literature (Duflo et al., 2009; Laderach et al., 2011). Schultz's (1964) "poor but efficient" hypothesis that small farmers in traditional agricultural settings respond positively to price incentives by efficiently allocating their resources has been an enduring theme in agricultural development economics for many decades. But beyond price incentives, successful adaptation will also depend on: (a) farmer attitudes and preferences and (b) their binding constraints to investment.

Climate change will intensify already existing vulnerabilities, and although farmers in developing economies have shown that they can respond to short-term changes in environmental conditions, they may not have the ability to cope with events of a transnational nature without support (Challinor et al., 2007). For this reason, the development of institutions, both formal and informal, play an instrumental role in influencing the livelihoods and the resiliency of rural households. These institutions can help to determine whether climate change adaptation responses are organized collectively or individually, the emergence of leadership in different contexts, and the mediation of external interventions into a local context (Agrawal, 2010).

Even when farmers are willing improve their adaptive capacity by adopting (potentially risky) new technologies and practices, they may face binding constraints that will make it hard or impossible to do so, such as high transaction costs, poor physical infrastructure, lack of access to inputs and seeds, and low levels of institutional support and capacity (Hazell et al., 2010). For example, although crop diversification can help to mitigate the impacts of climate change, Bradshaw et al. (2004) find that farmers increasingly specialize their production systems when faced with economic factors such as high start-up costs and economies of scale.

Risk aversion and barriers to investment can both be lowered by improving farmer access to information and knowledge (related to production, marketing, etc.). Often this knowledge already exists within the farming communities in the form of local knowledge about seasonal patterns that determine how and when to plant and apply inputs; but some of this knowledge will have to come from outside the local communities, such as through trainings on climate smart practices or through other extension services (Challinor et al., 2007).

Moreover, institutional capacity is needed to produce long term strategic interventions that facilitate networking, information sharing, and the creation of safety nets. The formation of agricultural cooperatives, for example, has been successful in helping smallholder farmers to overcome barriers associated with access to inputs, financial services and market participation, through the dissemination of inputs, loans, and training opportunities (Abebaw and Haile, 2013). Community-based natural resource management strategies can also enhance the adaptive capacity of farmers by creating social networks that are essential for coping with extreme events and by retaining the resilience of ecological systems (Tompkins and Adger, 2004).

Among crops that will see a shift in suitability, coffee has received much attention, given its importance in the global market and the large number of smallholder producers worldwide that depend on it as a main source of income. Coffee has long been known as a commodity product with a large footprint in poor countries in the tropics, and as a leading source of economic growth for many of them. At a global scale, it is considered one of the most traded commodities (Ponte, 2002). As the climate changes, coffee regions will be characterized by seasons marked with higher temperatures, erratic and severe rainy seasons, and longer periods of drought. All of these changes will impact coffee production and the farmers that depend on it, as the coffee tree is vulnerable to droughts, excessive rain, and temperature extremes (Conde et al., 2013).

This study presents results of an analysis of the vulnerabilities of smallholder coffee producers in Nicaragua to climate change; and I study their capacities to build adaptive strategies in response to these changes. In this study I use descriptive analyses and experimental economic methods – risk games - to evaluate the preferences, attitudes, and capacities of coffee producers in Nicaragua to build adaptive capacity to climate change. I show that food insecure households are more risk averse than those that are not food insecure and that much improvement is needed in the sector in terms of equity and institutional development.

The remainder of this chapter is organized as follows: in Section 2 I discuss the coffee sector in Nicaragua and how it is expected to change as a result of climate change, and I provide a brief literature review of farmers' behaviors under conditions of scarcity. In Section 3 I describe the study site and data collection methods. Section 4 focuses on the economic games that are used to assess attitudes towards risk. Section 5 presents the results and a discussion about the findings. I conclude with a review of policy implications and recommendations for future research.

Background

Coffee in Nicaragua

Nicaragua is one of the poorest countries in Latin America with more than 42% of the population living under the poverty line and most in rural areas (World Bank, 2016). Coffee in Nicaragua is by far the most important crop in the economy, and is the highest source of agricultural export revenues in the country. There are more than 48,000 coffee producers in Nicaragua, producing mostly Arabica coffee, the majority of them farm on plots of less than 3.5 hectares (Valkila and Nygreen, 2010). The economic dependence of smallholder farmers on coffee cannot be overstated.

Climate change is expected to affect a large proportion of coffee growing areas in Nicaragua, which will be marked by greater seasonal variability in temperatures and precipitation. Areas of Nicaragua, including Matagalpa, will see up to 60% decrease of area suitable for coffee production (Laderach et al., 2011).

For vulnerable households suffering from food insecurity and at the mercy of market and climatic fluctuations, finding a pathway to resilience and adaptability is urgent and the only way forward. Earlier research by Laderach et al. (2011) has identified the potential pathways for these farmers to improve their income potential; they include: (a) the adoption of coffee production practices that will improve their adaptive capacity to climate change, or (b) moving from coffee production altogether to a different high value crop, such as cocoa, which can maintain or increase their current income, or by (c) dropping out of agricultural production and finding non-farm employment (perhaps still related to agriculture).

The search for adaptation strategies within agricultural systems has mostly focused on technical and productivity interventions – such as the development of forecasting systems, and changes in the location of production (Perfecto and Vandermeer, 2015). Less common, however, is the recognition that farm management practices can significantly contribute to improved adaptation by producers through, for example, the adoption of integrated pest management and through the incorporation of shade into coffee farms. Evidence has shown that agro-ecological management practices can significantly improve resiliency to climate change (Perfecto and Vandermeer, 2015; Philpott and Dietsch, 2003).

For example, in a study of 880 paired experimental plots in Nicaragua, Holt-Gimenez (2002) found that after Hurricane Mitch hit the country in 1998, plots that had been following Sustainable Land Management (SLM) practices were able to recover more quickly than plots conventionally managed. SLM includes a variety of soil conservation, agro-ecological and agroforestry practices that generally avoid external inputs. The study finds that farms following SLM practices had more topsoil, higher field moisture measures, more vegetation within the system and lower economic losses than the conventional plots.

Explaining Farmer Behavior under Conditions of Scarcity

Farmers may have attitudes and preferences that prevent them from taking steps that will ensure their long run viability. Among these, we know it is known that their attitudes toward taking risks are paramount. Poor households are living at the margin and are often highly risk averse – and for good reason. They can be one exogenous shock (e.g. climate shock or market fluctuation) away from losing most or all of their assets (Tanaka et al., 2010). With each sequential shock, compounded upon previous shocks and vulnerabilities, these household are at risk of spiraling downward and falling into a poverty trap from which they cannot easily emerge (Carter and Barrett, 2006).

The question of uncertainty and risk in the adoption of new agricultural technologies has been explored extensively in the literature. Risk aversion – argued to be a direct result of socio-economic conditions (Yesuf and Bluffstone, 2009) - has often been considered a major factor in reducing the rate of adoption (Wossen et al., 2015; Duflo et al., 2009; Marra et al., 2003; Feder et al., 1985). In a study by Ayenew et al. (2015) the authors find that risk behavior is significantly and positively associated to on-farm diversification in Ethiopia, in other words, that farmers who are willing to take risks are more likely to also incorporate additional crops into their farms. In Peru, Engle-Warnick et al. (2007) find that risk averse farmers are less likely to adopt new, higher yielding, potato varieties. In a large study across multiple countries in Latin America, Cardenas and Carpenter (2013) find that women are more risk averse than men and the older participants are more willing to take risks than younger participants. Understanding attitudes towards risk, therefore, can provide important insights into why and when farmers may choose to adopt new technologies and production practices.

Much of the literature about risk aversion has been motivated by the proposition that poverty can be explained by risk aversion, or that people remain poor due to preferences and attitudes that are incompatible with growth (Thaler, 1997), or that people are too risk averse to take the opportunities and chances needed to increase their resources and improve their wellbeing (Cardenas and Carpenter, 2008). Yet in an extensive review of the experimental literature, Cardenas and Carpenter (2013) find that the literature does not support this proposition, in fact, they find very little evidence that poor people in developing countries are more risk averse than others.

On the one hand, some studies have found that there is a relationship between income and risk aversion, mainly, that lower income households are more risk averse than higher income households (Tanaka, 2010; Hartog et al., 2002; Donkers et al., 2001; Moscardi and De Janvry, 1977). On the other hand, another set of similar studies have been unable to show this relationship, and do not find that poor households are more risk averse than other households (Bosch-Domènech and Silvestre, 2006; Henrich and McElreath, 2002)

A related and important area of research, therefore, also studies how scarcity affects behavior and attitudes. In a study of behavior under scarcity Haushofer and Fehr (2014) state that material scarcity detrimentally changes people's allocation of their attention, affecting their behavior and decision-making. Agarwal (2000) finds that households facing the most financial constraints would steal wood from a protected forest, and risked getting caught and getting a fine, in order to provide cooking fuel for their homes, exhibiting riskier behavior. While Levy et al. (2013) find that a person who on average tends to be risk tolerant (willing to take risks) when he/she is not deprived of food, will shift towards high risk aversion, when they experience hunger and deprivation.

This study contributes to this body of research by examining the risk perceptions of coffee farmers in Nicaragua who are suffering from severe food insecurity. I use experimental games to measure risk aversion, and use the results of these experiments, with a series of descriptive analyses to analyze the capacities and incentives of coffee producers to seek adaptive strategies to address climate change.

Description of the Study Site and Sample

This study was conducted in the department of Matagalpa in northern Nicaragua between June and July 2015. The department of Matagalpa is divided into 13 municipalities that contain one or more communities, the smallest administrative unit. A sample of 236 households was selected using a two stage stratified random selection strategy. First, communities in Matagalpa were stratified by level of vulnerability to climate change. Vulnerability was determined by the average elevation in which the community was located. Higher elevation (above 1000 meters above sea level) had a lower vulnerability index than those at lower elevations, as households in higher elevations will be less affected by increased temperatures. In this first stage, a random sample of communities was selected based on their vulnerability index. In the second stage, households in each of the selected communities were drawn from a census listing of coffee producers in the region. The households surveyed in this study form part of an ongoing project on climate change and food security conducted by the International Center for Tropical Agriculture (CIAT). From the sample of 236 households, 88 households were randomly selected to participate in the risk experiment.[2] Table 1 compares the two groups (participants and non-participants) across a set of key demographic and farm characteristics. The data show that there are no statistically significant difference between the two groups, confirming that the subsample introduces no measurable bias to the risk experiment analysis.

Table 1. Characteristics of Game Participants and Non-Participants

Variable	Non-Participant	Participant	p-value
HH Size	5.34	5.59	0.39
Education	3.49	4.22	0.14
Table 1(Cont'd)			
Age	45.41	48.11	0.19
Total Income	157,879	238,415	0.19

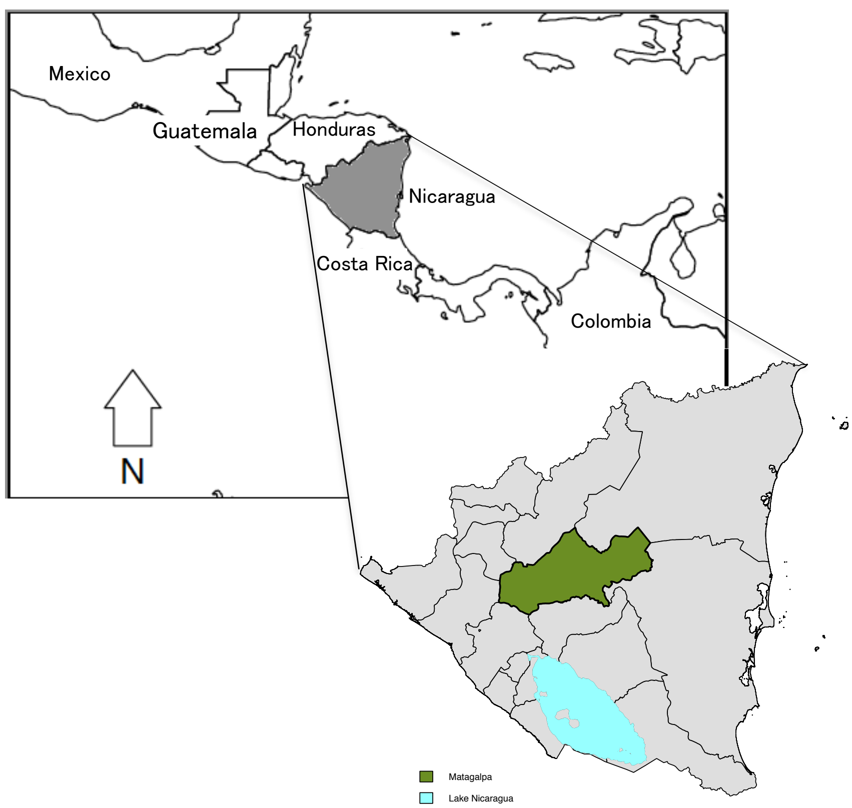
[2] Due to budget constrains it was not possible to conduct the experiments with 236 households.

Table 1 (cont'd)

Area	8.86	10.95	0.19
Coffee Experience	16.12	16.93	0.63
Male	66.2%	64.7%	0.82

After eliminating households for which data were missing or incomplete, the data set for this analysis was reduced to 221 households for the surveys overall, and 82 for the risk experiments. Nine out of 13 municipalities are represented in the data; municipalities not sampled were in regions of Matagalpa where coffee is not grown. A map of the study area is presented in Figure 2.

Figure 2. Map of Study Area



Producer information was collected on, among other things, demographic and socio-economic characteristics, agricultural production, and experiences with economic and climatic shocks. Table 1 summarizes some of the characteristics of the producers in the sample. The average age of the respondents is 46 years with an average of 3.8 years of formal education completed. The mean area under production is 4.85 hectares and the mean annual coffee production is 9.7 quintales (312.8 kg) of wet parchment[3] per hectare. Forty-six percent of the sample are members of a coffee cooperative and 65% are male-headed households.

Table 2. Sample Characteristics

Variable	Means (% where noted)	
Male	65.4%	
Age	46.4	(15.28)
Household Size	5.4	(2.12)
Years of Education	3.8	(3.48)
Years in Coffee	16.5	(12.48)
Total Coffee Income (USD) per ha	821.8	(875.11)
Total income (USD)	5,648.3	(7,377.11)
Total area under coffee production (ha)	4.8	(5.38)
Total Coffee Production (quintales[1]) per ha	9.7	(120.59)
Cooperative membership	45.5%	

[1] *1 Quintal= 46kg; Standard deviations are presented in parentheses*

In addition to these primary data, I use data for two variables provided by the International Center for Tropical Agriculture (CIAT): (1) an indicator of household vulnerability to

[3] Wet parchment is a state of the coffee in its transformation from cherry to bean. After harvesting, the freshly harvested cherries are passed through a pulping machine to separate the skin and pulp from the bean. After depulping, the bean is transported to water filled tanks for fermentation where they remain from 12 to 48 hours. When fermentation is complete, the beans are rinsed and are ready for drying. Coffee at this stage of the wet milling process is known as wet parchment.

climate change which takes into consideration predictions of temperature changes in 2020 and 2050 in combination with the elevation at which the household is located.; (2) an indicator of household food insecurity that is based on whether households have had to compromise the quality and quantity of the food consumed by the adults and the children in the household.

Description of the Framed Field Experiments

Economic experiments were used to measure attitudes towards risk by observing the behavior of farmers in a set of one-period lottery games with real pay-offs. The experiments were designed with gains-only payoffs; farmers playing these experiments are very poor and should not be to put in a situation in which the worst possible loss exceeds their current cash holdings.

Following Binswager's (1980) design, I conducted one lottery choice experiment intended to assess participants' attitudes towards risk. In the game, the participant was shown a lottery choice on a laminated card with six different possible binary payoffs and asked to pick one to play. To avoid problems that might arise if participants had a hard time understanding probabilistic outcomes, a simple 50-50 chance scenario was presented to the producer.

The risk experiment was framed as a situation in which the farmer makes a decision about his/her coffee production given uncertain future climate. Interviewers told farmers that due to uncertain weather, the yield from the upcoming coffee season would be affected in such a way that the likelihood of crop failure and crop success were the same (equal probability). Farmers had the choice to follow one of six paths of action, given this uncertainty.

Table 2 describes the parameters of the experiment and method employed. Holt and Laurie (2002) suggest that a good starting point to determine the payoff levels is to use the daily pay rate of a farmer in the region where the study will be conducted. At the time of the study, a farmer in the regions earned an average of C$100 a day (100 Nicaraguan Córdobas, or approximately 3.77USD). Once the starting point was determined, the remaining payoff options were determined following recommendations from Yesuf and Bluffstone (2009).

Table 3. Risk Experiment Payoffs and Risk Coefficient

Choice	Payoffs		Expected payoff	Risk Aversion Class	Coefficient of Relative Risk Aversion
	Bad Harvest (p=0.5)	Good Harvest (p=0.5)			
1	100	100	100	Extreme	r > 2.96
2	80	150	115	Severe	2.96 ≥ r > 0.78
3	60	190	125	Intermediate	0.78 ≥ r > 0.62
4	40	240	140	Moderate	0.62 ≥ r > 0.49
5	20	300	160	Slight	0.49 ≥ r > 0.23
6	0	350	175	Neutral to Preferring	0.23 ≥ r

**1USD = 26.5 Córdobas in July 2015 when the experiments were conducted*

The constant relative risk aversion utility function, $U(x) = \frac{x^{(1-r)}}{1-r}$, is used to measure the risk attitudes at which people should be indifferent between any two neighboring lotteries. For example, the relative risk aversion *r* that would make one indifferent between the first and second lotteries (or in other words, the utility of any lottery does not exceed the utility of getting the average monetary payoff of the lottery with certainty) is calculated as follows:

$$U(100) = U(80) + U(150)$$

$$\frac{100^{(1-r)}}{1-r} = \frac{1}{2} * \frac{80^{(1-r)}}{1-r} + \frac{1}{2} * \frac{150^{(1-r)}}{1-r} = 0, r = 2.96 \quad (1)$$

Experiment Mechanics in the Field

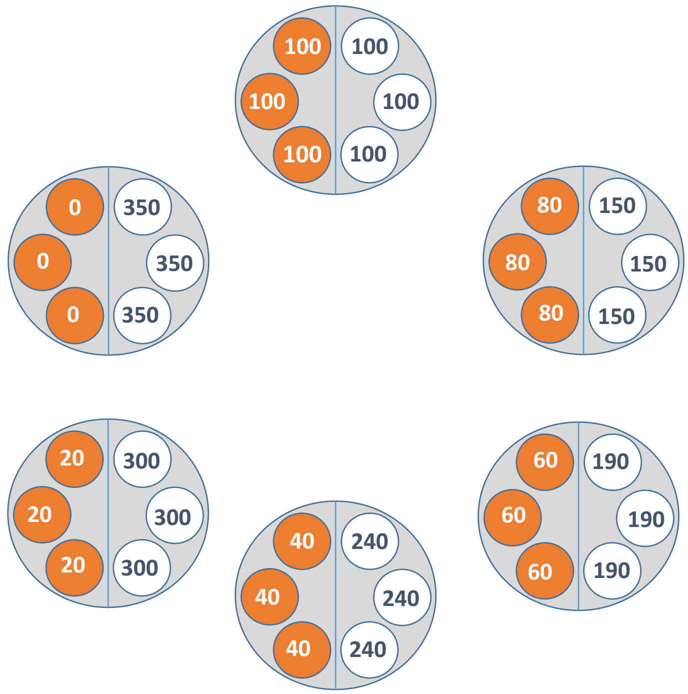
The experiments were conducted at the farmer's house, preceding the survey and they took close to thirty minutes to complete. The information from the surveys and experiments were registered in tablets by the enumerator.

I started the experiment by describing the task as a situation in which the farmer had to make a decision regarding his coffee production that would involve some risk of crop success or crop failure. All possible outcomes were described before the farmer had to make a decision. Farmers were shown a laminated card (Figure 3) containing the risk lottery that had 6 possible alternatives. Farmers had to choose one of the 6 different alternatives, which in turn had two potential outcomes (depending on the crop success or crop failure). The alternatives were: with alternative (1) the farmers simply received C$100, in other words, the payoff was the same regardless of the outcome of the game;

with alternative (2) the farmer could receive either C$80 or C$150, in other words, by not choosing (1) the individual stood to lose C$20 but could also gain C$50. The payoffs for alternatives 3, 4, and 5, were 60/190, 40/250, and 20/300, respectively. Finally, by choosing (6) an individual could either receive no money at all or get C$350. Each choice is associated with a classification of a risk class, from risk averse in alternative (1) to risk neutral-to-preferring in alternative (6) as shown in Table 2. The payoffs for each lottery choice were chosen so that the expected payoff and the variance of each lottery increases in clockwise order.

In addition, the enumerator had a bag with equal number of white and orange balls, and once the farmer decided on the lottery that he/she wanted to play, he/she randomly drew a ball from the bag to determine the payoff for the activity. If the farmer withdrew an orange ball they received the low payoff, if he/she withdrew a white ball they received the high payoff.

Figure 3. Risk Experiment



Payoffs from the experiment were paid in cash. In average I paid farmers 150.25 Nicaraguan Córdobas (or 5.77USD), an amount consisting of the average wages for 1.5 days.

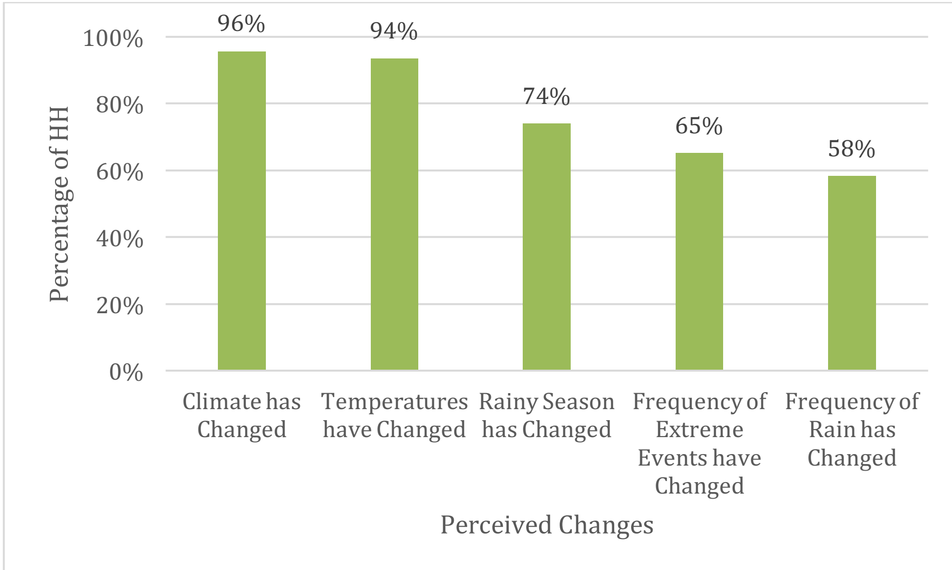
Results and Discussion

In addition to results from the experiments, in this section I present a series of descriptive analyses that help us understand Nicaraguan coffee producers' perceptions about climate change and to shed some light on the capacities that they have to mitigate its impacts.

Descriptive Analyses

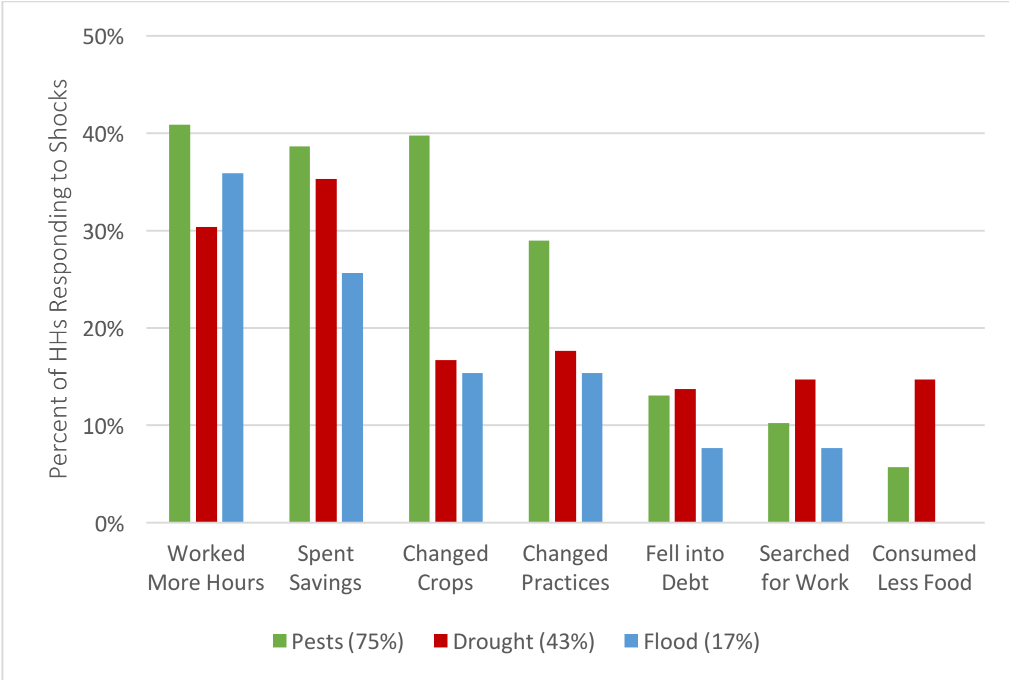
I begin this section by examining how all farmers in the sample have perceived changes in the Matagalpa climate over the past ten years. Overall, most farmers have perceived major changes in regional climate patterns; over 90% of households stated that they have seen changes in overall climate, and in temperatures specifically, over the past ten years. A majority of famers have also perceived temporal changes in the rainy season (74%) as well as changes in the frequency of rainfall (58%). Furthermore, 65% of households believe that the frequency of extreme events has changed over the past 10 years (Figure 4). The direction of these changes are estimated based on field observation during field visits and data collection, many farmers talked about recent droughts that had destroyed their maize and bean plantations (changes in the frequency of rainfall - fewer), and of early rains that caused their coffee trees to flower early (temporal changes in the rainy season). Farmers, due to the nature of their work, have their finger on the pulse of the weather and the land they work, and although they may not be aided by computerized tools and models to measure or estimate climatic events, their experience has taught them to recognize patterns and changes that affect the production of their crops. As seen with the households from this study, the vast majority of them have concluded that there have been changes in the climate, both in frequency and in the timing of those events.

Figure 4. Perceptions About Climate Change



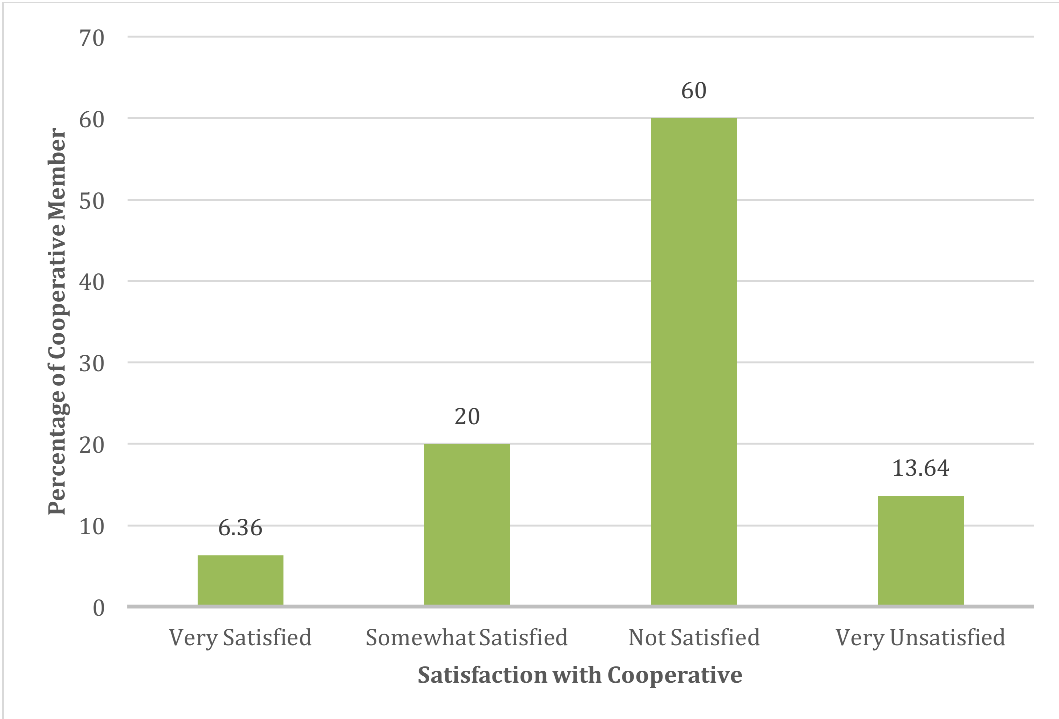
Despite the high proportion of farmers reporting changes in weather patterns, a smaller proportion of them reported experiencing losses due to these changes over the past 5 years (Figure 5). Of the surveyed households, 75%, 43% and 17% reported experiencing pests, droughts, and floods (respectively) in their coffee fields. The most common overall response to these shocks is for producers to increase the number of household labor hours and to spend their savings to cope with losses. In addition, 40% of farmers who experienced pests switched to a different crop or to a new coffee variety and 29% of them changed their production practices to respond to the pest (e.g., applying more pesticides, pruning, or stumping coffee trees). Fifteen percent of households experiencing droughts had to decrease their food consumption. It is likely that these are households that grow subsistence crops, such as beans and maize in addition to coffee. Overall, farmers respond to pests at a higher rate than to droughts and floods, most likely due to the institutional response and support in the area to the recent leaf rust epidemic.

Figure 5. Responses to Climate Shocks



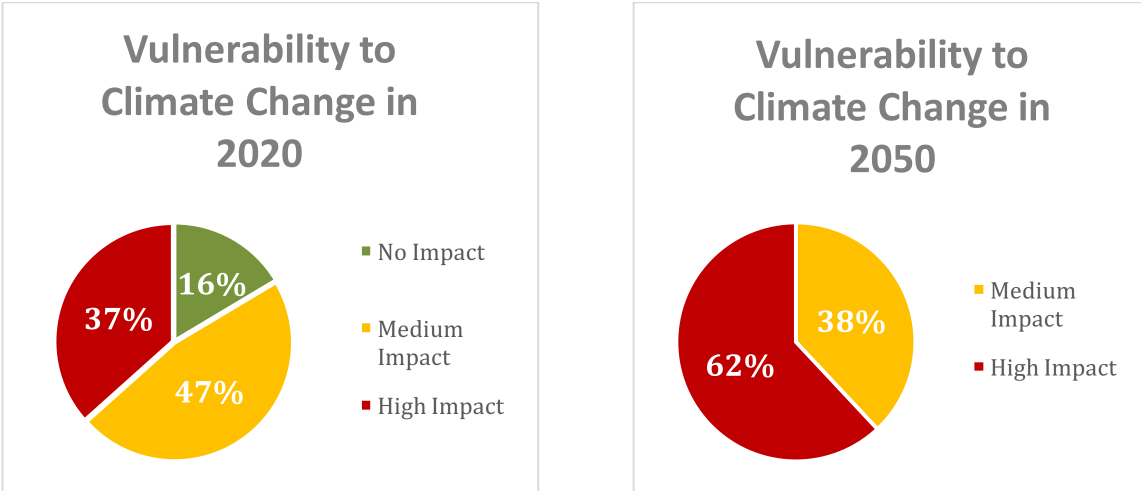
Cooperatives, through the support that they can provide in the provision of inputs, trainings, and other extension services, can play an important role in helping farmers to transition towards more resilient livelihoods. The sample in this study is evenly split between cooperative members and non-members, with 45.5% of farmers belonging to a coffee cooperative. Of these cooperative members, however, 60% have expressed being dissatisfied with their cooperatives, and a paltry 6.4% of them stated that they were very satisfied with their cooperatives (Figure 6). Issues of trust, transparency, lack of support, and corruption have all come up in the literature on cooperatives in Nicaragua (Bacon, 2010), and these results confirm that to some extent these are lingering issues for coffee farmers in the country.

Figure 6. Member Satisfaction with Cooperative



Moving beyond farmer perceptions and preferences, I focus on an indicator of climate change vulnerability (developed by CIAT) that allows us to examine the degree to which respondents in this sample are currently living in areas that are at risk of suffering losses due to climate change impacts. I find that by 2020, 16% of households located in Matagalpa will not see any significant impacts due to climate change, while 47% of them will see medium impact, and 37% will see high impacts induced by climate change. The situation becomes even more dire in 2050, by which time everyone in this sample will be located in regions estimated to be impacted by climate change, with the majority of them (62%) experiencing high impacts (Figure 7).

Figure 7. Percentage of Household Vulnerable to Climate Change Shocks



In addition to vulnerability to climate change, data from this study indicates that 88.6% of households in the sample are severely food insecure, and have had to lower the amount of food consumed and also compromise the quality of the food they consume at home.

Men and women respond to shocks differently, and their vulnerability to these shocks is also different. Women, in addition to restrictions that they face due to cultural norms (such as not being able to own land, or responsibilities as homemakers and primary caregivers of children and the elderly), often have lower access to extension services and fertile land (Ruben and Zuniga, 2011; Bacon, 2010). When I standardized yield and income in the sample by the amount of land operated by the household, I find that women heads of households hold significantly less land (1.66ha vs. 2.77ha), which produces less coffee (10.02 quintales vs. 13.03 quintales), in turn generating less income (568.9USD vs. 952.3USD). Additionally, women are significantly more food insecure than men. Of the survey respondents, 96% of female headed households suffered from food insecurity versus 85% of male headed households (Table 3).

Table 4. Gender Differences

	Male	Female	p-value
Average Area Under Coffee Production (ha)	2.77	1.66	0.002
Average Yield per Hectare of Coffee (kg)	599.38	460.92	0.086
Average Income Per Hectare of Coffee	952.30	568.90	0.001
Percentage of Farmers Suffering from Food Insecurity	85%	96%	0.019

Experiment Results

I use an ordered probit model to examine the determinants of farmer risk preference. The econometric specification for this model is presented below:

$$\begin{aligned} Risk_i = {} & \beta_1 HHSize_i + \beta_2 Sex_i + \beta_3 Education_i + \beta_4 Age_i + \beta_5 \text{Income}_i + \beta_6 Income_i^2 \\ & + \beta_7 Area_i + \beta_8 Experience_i + \beta_9 Food\ Insecurity1_i \\ & + \beta_{10} Food\ Insecurity2_i + \varepsilon_i \end{aligned} \tag{2}$$

$Risk_i$ represents individual *i*'s choice from 1 to 6 in the risk activity, and where a higher value represents higher riskiness. β_i represents the estimated coefficient for each regressor and ε_i is stochastic component of this model. The model includes household demographics, farm characteristics, and a dummy variable indicating level of food insecurity experienced by households.

I begin the analysis of risk preferences by looking at the distribution of risk choices among the different variables in the model (Table 4). On average, smaller households, older people, and farmers with less land under coffee production are more likely to choose the less risky option, while more educated households and men tend to choose the riskier options. There is no clear trend of risk choices for different income levels, the average income for the less risky choice is the highest in the group, yet it decreases after the first option and then goes back up for the riskier choice.

Table 5. Distribution of Risk Choices

	Low Risk←---→*High Risk*					
	Choice 1	Choice 2	Choice 3	Choice 4	Choice 5	Choice 6
HH Size	6.2	5.1	6.2	5.4	4.4	5.0
Male	57%	75%	68%	56%	63%	80%
Education	3.3	4.2	3.6	4.5	6.4	5.0
Age	51.8	43.9	47.5	47.9	47.4	47.6
Total Income (USD)	18,807	5,721	3,162	6,896	6,925	10,371
Total Area (ha)	11.4	4.6	4.6	9.1	6.4	7.6
Coffee Experience	13.5	14.0	20.3	17.2	18.6	19.3

When the lotteries are numbered in increasing riskiness from one to six, clockwise, the average choice in the risk game is 3.1 which puts the average close to the 60|90 gamble.

A quick look at the distribution of choices and food insecurity helps us understand how these households made their choice selections (Figure 8). Households with no food insecurity tend to make riskier choices, while households suffering from severe food insecurity consistently select the less risky options. Not a single household in the sample that belonged to the highest food insecurity category chose option 6 in the game. Table 5 presents the results from the econometric model.

Figure 8. Game Choices by Households with Food Insecurity

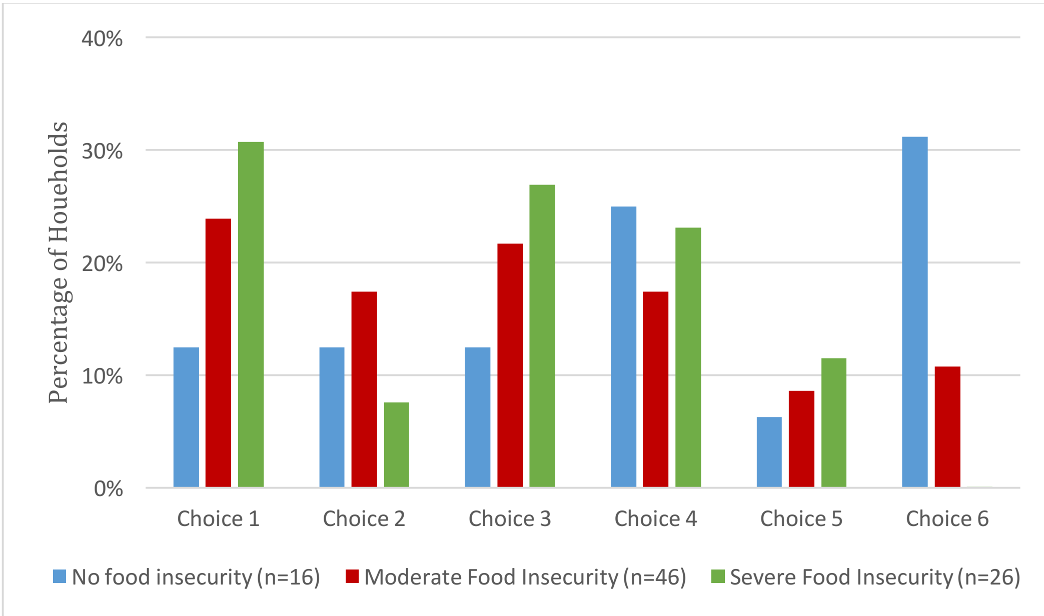


Table 6. Results from Ordered Probit Model for Risk Aversion

	Coefficient		Std. Error
HH Size	-0.258	***	0.106
Male	-0.069		0.444
Education	0.027		0.064
Age	-0.017		0.017
Income	0.005	*	0.003
$Income^2$	-4.28e-6	**	1.92e-6
Total Area	-0.027		0.020
Coffee Experience	0.036	*	0.022
Moderate Food Insecurity	-2.436	***	0.765
Severe Food Insecurity	-2.237	***	0.838
Log Likelihood	*-127.56*		
Chi-square	*28.50*		
n	*82*		

*Note: ***, **, and * represent significance at the 0.01, 0.05, and 0.1 confidence level respectively*

From the probit model a number of important findings can be seen: Men, higher educated respondents, and younger respondents tend to have a higher likelihood of selecting the riskier options. Households with more land, however, have a higher likelihood of choosing the less risky option, although the differences are not statistically significant.

Larger households with more members are significantly more likely to “play it safe” in their choices. With each additional household member, the likelihood of selecting the riskier C$0|C$350 choice decreases by 14.7%. Larger households face constraints that might explain this choice, for example, larger households may have a higher proportion of dependents (children and elderly) and are not, therefore, willing to take the risks that they would take if they did not have any dependents. Any risks that they take could affect a higher proportion of vulnerable household members, as explained in findings from a study of risk attitudes and preferences of agricultural households in Ethiopia (Yesuf and Bluffstone, 2009), where large households with a higher proportion of elderly and young children showed higher risk aversion than other households.

As household income increases, so does the likelihood of the selection of riskier options in the game. The significance of the square term in the model points toward a curvilinear relationship between risk and income. In other words, although there is a higher likelihood of selecting a riskier option for higher income households, this positive trend occurs at a decreasing rate.

Finally, severely food insecure and moderately food insecure households are 158% and127% less likely to select a risky choice, respectively, than households that do not suffer from food insecurity. This result can be interpreted in two ways: on the one hand these results are encouraging because it means that households that are already vulnerable are less likely to risk exacerbating their vulnerabilities by engaging in risky behavior. On the other hand, this risk aversion could mean that vulnerable households will be less likely to engage in activities that they may deem risky but that could potentially have great benefits to their wellbeing, for example, the adoption of new technologies or practices that could help them become more resilient to climate and market shocks.

Given that there is still no consensus about the relationship between risk aversion and poverty (Cardenas and Carpenter, 2008), the results from this study can contribute to this body of research in the literature. In agreement with several previous studies (Tanaka, 2010; Hartog et al., 2002; Donkers et al., 2001; Moscardi and De Janvry, 1977), the present research shows that poor households are more risk averse than non-poor. An important contribution from this study is that even when income is controlled for, the degree of household food security emerges as a significant determinant of risk aversion, in other words, the household's capacity to provide nutritious food without uncertainty about food access and availability in the future helps to determine whether the household may be more or less risk averse.

Not many studies that measure the effect of food insecurity on risk attitudes have been found, but these results are consistent with similar studies that have accounted for food insecurity and hunger and their relationship with risk (Levy et al., 2013; Onyemauwa et al., 2013)

Conclusion

How will coffee farmers in Nicaragua face the growing threat of climate change? Will they be prepared? Will they know what to expect? In this paper I examined the perceptions, capacities, and attitudes (including risk aversion) of coffee producers towards climate change and the mitigation of its impacts.

The situation in which coffee producers in Nicaragua find themselves is dire. There is already a high level of food insecurity; compounding this, they live in a region of the country that is experiencing climate change and will see medium to severe impacts from weather and climatic events in the coming decades. The suitability of their coffee farms to the changing environment will continue to decline, threatening their income potential and food security even further.

Farmers are already experiencing droughts, floods, and pests and some have had to respond by increasing the number of work hours that they dedicate to their fields. This additional physical labor (mostly) can result in potential health loss due to accidents, longer exposure time to chemical inputs, and lack of proper nutrition to support their increased physical exertion. Adding to this vulnerability, some of these farmers have also responded by decreasing their food consumption as a coping mechanism, a response that further jeopardizes their health and productive capacity.

This danger is especially acute for women. I find that women are significantly more food insecure than men, they own less land, produce less, and have lower income than their male counterparts. Policies designed to improve the adaptive capacity of farmers in the region must account for these differences by introducing interventions that directly address the barriers (cultural and economic) that women face (e.g., by developing interventions that depend on the participation of women). Further research is needed to examine specifically how gender differences affect adaptive capacity, and to guide the development of strategies that will be responsive to these differences.

My literature review suggests that institutions play an important role in providing services to smallholder producers through access to training opportunities and financial services. Yet, in this region, farmers have expressed high rates of dissatisfaction with their cooperatives and the services they provide. There is need for more research - and in particular participatory research – that systematically takes farmers reported experiences and attitudes into account in promoting equitable and efficient adaptive strategies.

Despite studies that have found that poorer agrarian households tend to be more risk averse than higher income households (Tanaka, 2010; Hartog et al., 2002; Donkers et al., 2001; Moscardi and De Janvry, 1977), many other studies have found the opposite (Bosch-Domènech and Silvestre, 2006; Henrich and McElreath, 2002). The literature on this issue is inconclusive. Furthermore, in a review of the literature, I find little research that explores risk aversion among households that are already highly vulnerable, especially households who are suffering from food insecurity. These results provide an important contribution to this debate. *While holding income level constant, I find that households that are severely and moderately food insecure are significantly less likely to make riskier choices than are those not suffering from food insecurity.*

The implications of these results should not be taken lightly, climate shocks can destroy crops, livestock, and other household assets; for households in chronic poverty, conventional risk management strategies simply may not be enough (Barrett et al., 2007). The challenge lies in the development and provision of services, institutions and interventions that enable the accumulation of productive assets and the adoption of improved agricultural production technologies that will be instrumental to building the capacity of households in their struggle to adapt to climate change.

Interventions that intend to reduce vulnerability to shocks should consider how households that are severely food insecure, perhaps already trapped in poverty, will respond to possible adaptation pathways and the inherent risks associated with them. An important recommendation for programs focused on helping the most vulnerable populations to adopt technologies and practices that can help with climate change emerges from this study. These programs must first address issues of food insecurity among poor households; by doing so, there is a non-negative likelihood that the targeted farmers will be more open to taking the risks associated with the adoption of new practices and technologies.

While the results reported from this analysis help us to assess how risk and food security combine to affect potential farmer decisions concerning the adoption of climate change friendly practices, I must acknowledge that the research is not without limitations. First, the number of participants in the experimental games is small, information from only 82 farmers is used in the econometric analysis. Future research on a larger sample of participants will help to validate the results of this study. Second, food security data on the study households was collected a year earlier than other data presented in this analysis. This lag loses any changes in the food-security related conditions surrounding these households. In other words, households identified as food insecure in this study, may not have been food insecure at the time of the risk activity, thus potentially diluting the strength of the coefficients reported and the relationships they represent. Finally, although these experiments attempt to emulate real life behavior and measure how farmers respond to risks, farmers may not feel the same way about taking a relatively small risk presented to them by the enumerators of the study as they would about a decision that could lock them into poverty in real life, or help them rise from poverty. To further explore the relationships revealed in this study between risk, food security and climate change adaptation I see the need for a more qualitative approach, one that will provide deeper insight into how coffee producers evaluate the potential risks and rewards of adopting alternative practices and how, in turn, cooperatives and other institutions can work more effectively to support them in their decisions.

REFERENCES

REFERENCES

Abebaw, Degnet, and Mekbib G. Haile. "The impact of cooperatives on agricultural technology adoption: Empirical evidence from Ethiopia." *Food policy* 38 (2013): 82-91.

Agrawal, Arun. "Local institutions and adaptation to climate change." *Social dimensions of climate change: Equity and vulnerability in a warming world*(2010): 173-197.

Agrawal, Arun. "Common resources and institutional sustainability." *The drama of the commons* (2002): 41-85.

Agarwal, Bina. "Conceptualising environmental collective action: why gender matters." *Cambridge journal of economics* 24.3 (2000): 283-310.

Araral, Eduardo. "What explains collective action in the commons? Theory and evidence from the Philippines." *World development* 37.3 (2009): 687-697.

Ayenew, Habtamu Yesigat, Johannes Sauer, and Getachew Abate-Kassa. "On Smallholder Farmers' Exposure to Risk and Adaptation Mechanisms: Panel Data Evidence from Ethiopia." *89th Annual Conference, April 13-15, 2015, Warwick University, Coventry, UK*. No. 204223. Agricultural Economics Society, 2015.

Bacon, Christopher M. "A spot of coffee in crisis Nicaraguan smallholder cooperatives, fair trade networks, and gendered empowerment." *Latin American Perspectives* 37.2 (2010): 50-71.

Bardhan, Pranab. "Analytics of the institutions of informal cooperation in rural development." *World Development* 21.4 (1993): 633-639.

Barrett, Christopher B., et al. "Poverty traps and climate risk: limitations and opportunities of index-based risk financing." (2007).

Barrett, Christopher B., and John G. McPeak. "Poverty traps and safety nets." *Poverty, inequality and development*. Springer US, 2006. 131-154.

Barrett, Christopher B., Barry J. Barnett, Michael R. Carter, Sommarat Chantarat, James W. Hansen, Andrew G. Mude, Daniel Osgood, Jerry R. Skees, Calum G. Turvey, and M. Neil Ward. "Poverty traps and climate risk: limitations and opportunities of index-based risk financing." (2007).

Blanco, Esther, Maria Claudia Lopez, and Sergio Villamayor-Tomas. "Exogenous degradation in the commons: Field experimental evidence."*Ecological Economics* 120 (2015): 430-439.

Bosch-Domènech, Antoni, and Joaquim Silvestre. "Do the wealthy risk more money? An experimental comparison." *Institutions, Equilibria and Efficiency*. Springer Berlin Heidelberg, 2006. 95-116.

Bradshaw, Ben, Holly Dolan, and Barry Smit. "Farm-level adaptation to climatic variability and change: crop diversification in the Canadian prairies."*Climatic Change* 67.1 (2004): 119-141.

Cardenas, Juan Camilo, and Jeffrey Carpenter. "Risk attitudes and economic well-being in Latin America." *Journal of Development Economics* 103 (2013): 52-61.

Cardenas, Juan Camilo, and Jeffrey Carpenter. "Behavioural development economics: Lessons from field labs in the developing world." *The Journal of Development Studies* 44.3 (2008): 311-338.

Carter, Michael R., and Christopher B. Barrett. "The economics of poverty traps and persistent poverty: An asset-based approach." *The Journal of Development Studies* 42.2 (2006): 178-199.

Challinor, Andrew, et al. "Assessing the vulnerability of food crop systems in Africa to climate change." *Climatic change* 83.3 (2007): 381-399.

Conde, Cecilia, Marta Vinocur, Carlos Gay, Roberto Seiler, and Francisco Estrada. "Climatic threat spaces in Mexico and Argentina." *Climate Change and Vulnerability and Adaptation: Two Volume Set* (2013): 279.

Ellis, Frank. *Rural livelihoods and diversity in developing countries*. Oxford university press, 2000.

Engle-Warnick, Jim, Javier Escobal, and Sonia Laszlo. "Ambiguity aversion as a predictor of technology choice: Experimental evidence from Peru."*CIRANO-Scientific Publications 2007s-01* (2007).

Donkers, Bas, Bertrand Melenberg, and Arthur Van Soest. "Estimating risk attitudes using lotteries: A large sample approach." Journal of Risk and Uncertainty 22.2 (2001): 165-195.

Duflo, Esther, Michael Kremer, and Jonathan Robinson. Nudging farmers to use fertilizer: Theory and experimental evidence from Kenya. No. w15131.

FAO, Comité Científico de la ELCSA. "Escala Latinoamericana y Caribeña de Seguridad Alimentaria (ELCSA): Manual de uso y aplicaciones." Roma: FAO(2012).

Feder, Gershon, Richard E. Just, and David Zilberman. "Adoption of agricultural innovations in developing countries: A survey." *Economic development and cultural change* (1985): 255-298.

Hartog, Joop, Ada Ferrer-i-Carbonell, and Nicole Jonker. "Linking measured risk aversion to individual characteristics." Kyklos 55.1 (2002): 3-26.

Haushofer, Johannes, and Ernst Fehr. "On the psychology of poverty." *Science* 344.6186 (2014): 862-867.

Hazell, Peter, Colin Poulton, Steve Wiggins, and Andrew Dorward. "The future of small farms: Trajectories and policy priorities." *World Development* 38, no. 10 (2010): 1349-1361.

Henrich, Joseph, and Richard McElreath. "Are Peasants Risk-Averse Decision Makers? 1." *Current Anthropology* 43.1 (2002): 172-181.

Holt-Giménez, Eric. "Measuring farmers' agroecological resistance after Hurricane Mitch in Nicaragua: a case study in participatory, sustainable land management impact monitoring." *Agriculture, Ecosystems & Environment* 93.1 (2002): 87-105.

Holt, Charles A., and Susan K. Laury. "Risk aversion and incentive effects."*American economic review* 92, no. 5 (2002): 1644-1655.

Intergovernmental Panel on Climate Change. *Climate change 2014: mitigation of climate change*. Vol. 3. Cambridge University Press, 2015.

Intergovernmental Panel On Climate Change. "Climate change 2007: impacts, adaptation and vulnerability." *Genebra, Suíça* (2001).

Laderäch, Peter, et al. "Predicted impact of climate change on coffee supply chains." The Economic, Social and Political Elements of Climate Change. Springer Berlin Heidelberg, 2011. 703-723.

Levy, Dino J., Amalie C. Thavikulwat, and Paul W. Glimcher. "State dependent valuation: the effect of deprivation on risk preferences." *PloS one*8.1 (2013): e53978.

Marra, Michele, David J. Pannell, and Amir Abadi Ghadim. "The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve?." *Agricultural systems* 75, no. 2 (2003): 215-234.

Moscardi, Edgardo, and Alain De Janvry. "Attitudes toward risk among peasants: an econometric approach." *American Journal of Agricultural Economics* 59.4 (1977): 710-716.

Onyemauwa, C. S., et al. "Risk aversion among farmers of the national program for food security in Imo State Southeast Nigeria." *Risk* 4.10 (2013).

Ostrom, E. "Ostrom, E. 1990. Governing the Commons: The Evolution of Institutions for Collective Action." (1990).

Perfecto, Ivette, and John Vandermeer. Coffee Agroecology: A new approach to understanding agricultural biodiversity, ecosystem services and sustainable development. Routledge, 2015.

Philpott, Stacy M., and Thomas Dietsch. "Coffee and conservation: a global context and the value of farmer involvement." *Conservation Biology* 17.6 (2003): 1844-1846.

Ponte, Stephano. "The 'Latte Revolution'? Regulation, Markets and Consumption in the Global Coffee Chain". *World Development*, 30(7), pp.1099-1122.

Prediger, Sebastian, Björn Vollan, and Benedikt Herrmann. *Resource scarcity, spite and cooperation*. Department of Economics (Inst. für Wirtschaftstheorie und Wirtschaftsgeschichte), 2013.

Ruben, Ruerd, and Guillermo Zuniga. "How standards compete: comparative impact of coffee certification schemes in Northern Nicaragua." *Supply Chain Management: An International Journal* 16.2 (2011): 98-109.

Santos, Paulo, and Christopher B. Barrett. "Informal insurance in the presence of poverty traps: Evidence from southern Ethiopia." Available at SSRN 998541 (2006).

Schultz, Theodore William. "Transforming traditional agriculture." (1964).

Tanaka, Tomomi, Colin F. Camerer, and Quang Nguyen. "Risk and time preferences: linking experimental and household survey data from Vietnam." *Behavioral Economics of Preferences, Choices, and Happiness*. Springer Japan, 2016. 3-25.

Thaler, Richard H. "Irving Fisher: modern behavioral economist." *The American economic review* 87.2 (1997): 439-441.

Tompkins, Emma L., and W Neil Adger. "Does adaptive management of natural resources enhance resilience to climate change?." *Ecology and society* 9.2 (2004): 10.

Uphoff, Norman, M. Wickramasinghe, and C. Wijayaratna. "" Optimum" participation in irrigation management: issues and evidence from Sri Lanka."*Human Organization* 49.1 (1990): 26-40.

Valkila, Joni, and Anja Nygren. "Impacts of Fair Trade certification on coffee farmers, cooperatives, and laborers in Nicaragua." *Agriculture and Human Values* 27.3 (2010): 321-333.

World Bank. (2016) Retrieved from http://data.worldbank.org/data-catalog/gdp-ppp-based-table

Wossen, Tesfamicheal, Thomas Berger, and Salvatore Di Falco. "Social capital, risk preference and adoption of improved farm land management practices in Ethiopia." *Agricultural Economics* 46.1 (2015): 81-97.

Yesuf, Mahmud, and Randall A. Bluffstone. "Poverty, risk aversion, and path dependence in low-income countries: Experimental evidence from Ethiopia." *American Journal of Agricultural Economics* 91.4 (2009): 1022-1037.

Chapter 3: Adaptive Capacity to Climate Change: Coffee Farmer Preferences for Crop Diversification in Nicaragua

Introduction

Coffee is grown in some of the most important biodiversity hotspots in the world (Perfecto and Vandermeer, 2015)—environments also known for their susceptibility to the negative impacts of climate change. Higher temperatures, droughts, and extreme and erratic rainfalls will all affect the suitability of these and other coffee producing regions, and intensification of farming systems compounds this effect by diminishing biodiversity which could otherwise help to mitigate some of these impacts. Moreover, coffee is produced by millions of farmers in the tropics, the majority of which are smallholder producers who depend on this crop as a main source of income. These three aspects of coffee production (biodiversity, climate change, and livelihoods) are intrinsically connected, and the study of any one must be carried out with an appreciation for its dynamic relationships with the others. Shade-grown coffee production management systems help to promote these three aspects of the human-environmental relationship in important ways: by preserving and promoting biodiversity richness, by helping coffee producers to build adaptive capacity to the negative impacts of climate change, and by providing alternative sources of food or income. Understanding the conditions under which producers are willing to adopt shade grown coffee production is of paramount importance given the overwhelming evidence that our climate is changing and that coffee producers are among those most vulnerable to its effects.

Farmers, households, and communities that are most prone to the negative impacts of climate change must take steps that will help them to mitigate these shocks. Yet adoption of mitigation strategies is not always simple; farmers often are forced to make difficult economic trade-offs under risky conditions and in an uncertain climate. Implicit in this problem is the fact that the impacts of climate change are compounded upon already existing vulnerabilities, so not only is their capacity to adapt lower, but the barriers that farmers face can be even more pronounced. For example, high rainfalls due to El Niño in 1998, followed by two years of erratic rainfall, forced farmers in Tanzania to give up maize production and instead sell their labor to more productive areas. Although in the short term this was a good coping mechanism for households, their dependence on labor as their sole endowment increased their long term vulnerability, since the resulting disease and malnutrition reduce their capacity for manual labor (ADB, 2003).

Farmers intensify when the value generated by the land is higher from a crop grown in it than from the forest that would otherwise occupy it (Tittonell and Giller, 2013). Unless farmers value the ecosystem services (such as biodiversity conservation) that shaded coffee farms provide over the value of their crop, they will be unwilling to adopt practices that help promote biodiversity conservation. Rural poverty is intertwined with biodiversity conservation, and different conservation programs and policies must deal with the threat of poverty and of economic tradeoffs required to mitigate that threat. At no time has this issue been more glaring than it is today, a time when farmers who depend on coffee as their main source of income are experiencing increased vulnerability to the impacts of climate change, and when the planet is seeing its highest rates of biodiversity loss in modern history.

In this research I use discrete choice experiments (DCEs) to study the preferences and behaviors among producers regarding the adoption of shade into coffee fields. DCEs allow the ex-ante analysis of the drivers of adoption, which in turn help to inform programs and other interventions designed to build farmer adaptive capacity in the face of growing climate threats. I use choice experiments in this study to examine the conditions under which farmers will be willing to diversify their coffee farms with shade crops. Given the vulnerability of coffee producers to pests, changes in market prices and climate shocks, understanding their incentives to adopt practices that will help them build better adaptive capacity to these shocks is of paramount importance. This study examines the tradeoffs that Nicaraguan coffee producers face as they consider alternative production strategies that will help them build that adaptive capacity.

Background

The coffee tree, especially the Arabica variety, grows at elevations ranging from 1300 to 1500 meters above the sea level and needs ample and consistent rainfall within a narrow temperature range. Coffee is prized by ecologists because it grows well under a canopy of shade trees, allowing for the development of rich biodiverse ecosystems. The value of shaded coffee lies in its capacity as a refuge for biodiversity; the push towards intensification of coffee production, however, has had dramatic impacts on the biodiversity composition of these traditional coffee farms (Perfecto et al., 2007).

In the 1970s and 1980s Latin America saw a rapid shift from polycultures to monocultures in the coffee sector in response to higher demand for coffee and to trade policies encouraged by the Global North (Perfecto and Vandermeer, 2015). In an effort to intensify coffee production, farmers radically reduced the number of shade trees in their farms, planting higher densities of new coffee varieties and intensifying the use of chemical inputs. An immediate effect of these practices was seen in the precipitous decline of migratory bird populations in North America and a decline in the richness of bird diversity in Latin America (Borrero, 1986). Despite the push towards intensification, studies have found a positive relationship between planned biodiversity in farms (such as farms with greater density of shade trees) and their richness of flora and fauna (e.g., vertebrates, invertebrates, plants and fungi) (Hernandez et al., 2013; Murrieta et al., 2013; Saldaña et al., 2013). Armbrecht et al. (2004) find that while it is generally beneficial to incorporate shade trees into coffee plantations, it is even better when there is a diversity of shade trees planted rather than just one variety. When diverse trees drop leaves and twigs onto the ground they find that there is a significant impact on consequent biodiversity of the flora and fauna in the fields. The importance of coffee production in enhancing biodiversity conservation is clear, but how coffee is grown also matters. Studies have found that shade-grown coffee farms in Mexico contain almost as much biodiversity as native forests, while sun coffee monocultures in Brazil are reported to be "biodiversity deserts" (Perfecto et al., 2009). As such, the authors find that in monoculture systems the most important physical factor contributing to the loss of species diversity is the direct effect of sunlight.

The incorporation of shade into coffee farms plays another important role besides biodiversity conservation. Shade systems also help store carbon from the atmosphere, and protect the watershed by reducing run-off and soil loss (Perfecto et al., 2007; Valkila, 2009). Moreover, planting trees on the farm can contribute to household livelihoods by generating products for human consumption (food security) and sales (income generation) (Mendez et al., 2010). A third advantage to shade-grown coffee is that it is known to be of higher quality (in the cup) and thus draws higher prices from coffee buyers, particularly those at the higher end of the specialty coffee market.

In addition to the ecosystem services that traditional coffee farms provide, farmers have yet another incentive to incorporate shade into their farms. Climate change scientists predict that tropical regions where coffee grows will be increasingly impacted by the changing climate, and as a result their suitability for coffee production will decline rapidly.

The adoption of climate change adaptation strategies is necessary, indeed, urgent, in some coffee growing areas. Regions that have already experienced periods of seasonal droughts will see a rise in the frequency of these droughts. Similarly, some areas will experience severe flooding due to increased and more intensive rainfall. In addition, changes in global temperatures will result in areas that will no longer be suitable for agricultural production at all (Fischer et al., 2002). No other population is more vulnerable to these changes than poor agrarian households that depend on agricultural production for their livelihoods. As the intensity and frequency of these events increase, the affected households will experience a loss of household assets and crops, declining access to water, and challenges to health and nutrition. Moreover, they will be left with less time to recover from the previous shocks, resulting in severe, potentially chronic, food insecurity (Laderach et al., 2013; Vermeulen et al., 2012; Fischer et al., 2002).

In this paper I use choice experiments to study the conditions under which coffee farmers would be willing to diversify their coffee farms with additional shade crop. This method has been used widely in the environmental and development economics literature. Birol et al. (2009) used choice experiments to estimate how Mexican maize growers valuate three components of traditional maize production practices (milpa): crop species richness, maize variety richness, and maize landraces. They find that while conservationists derive the highest value from traditional milpa production and the highest economic loss from GM maize adoption, marginalized maize producers receive little economic value from maize and crop diversification, and experience the smallest negative impact from the adoption of GM maize. Similarly, Ortega et al. (2016) use choice experiments to examine farmers' preferences for groundnut, soybean, and pigeon pea crop diversification in maize fields in Malawi. They find that farmers have significant labor constraints that limit their uptake of new crops to diversify their maize with, and that the uptake of legume and maize intercrop systems would increase if practitioners focus on legumes that have better marketability.

Coffee Leaf Rust in Nicaragua

The coffee leaf rust problem in Nicaragua and the rest of Mesoamerica has been devastating and merits special attention. Coffee in Nicaragua is grown mostly by small scale coffee farmers within the central mountains in Jinotega and Matagalpa, which are known for their rich volcanic soils and humid tropical climate. Farmers in this region depend on coffee production as their main source of income. In recent years, however, coffee in Nicaragua has been devastated by the coffee leaf rust fungus, and farmers have suffered large yield losses.

The leaf rust is caused by a fungus (Hemileia vastatrix) and although it originates from Sri Lanka, in Latin America it was first reported in 1970. The disease attacks Arabica coffee more severely than other varieties and it causes leaves to fall off and, when acute, can cause branches to die, resulting in heavy crop losses. The most significant outbreak of the disease in Latin America occurred during the closing months of 2012, with other outbreaks in the late 1980s, mid 1990s, and early 2000s. Some studies reported as much as 50% reduction of yields over a region that extends from southern Mexico to Colombia, during this latest outbreak (Cressey, 2013). Researchers surmise that a lack of proper economic incentives to invest in their farms (e.g., better credit, higher cherry prices, and lower input prices) as well as meteorological factors (such as earlier rainy seasons and rainy seasons interspersed with bright periods) have led to the string of coffee rust epidemics in Latin America (Avelino et al., 2015). This disease has impacted the coffee sector in Nicaragua beyond simple crop losses; it has resulted in wholesale changes in farmers' perceptions and behaviors, and much is still unknown about how these changes will affect the future of coffee production in the region.

Theoretical Framework

The empirical framework of this study is based on experimental choice modeling methods to analyze farmers' preferences for different coffee production strategies. In a choice experiment, respondents are asked to choose between option bundles containing a series of different attributes (of varying levels) from hypothetical choice scenarios. By controlling the variation in the levels of the attributes, researchers areI am able to analyze the choices made by the respondents and to estimate marginal values for the attributes presented in the choice sets.

The theoretical foundation of choice experiments is based on random utility theory, and relies on the assumptions of economic rationality and Lancastrian utility maximization (Lancaster, 1966). In the context of the present study, a coffee farming system is described as a collection of its physical and managerial characteristics, including the inputs applied and the crop diversity within the farm. By stating a preference for a specified farming system, faremrs are assumed to have chosen the alternative that will yield the highest utility or value to them. Random utility can be characterized by the following function:

$$u_{ijs} = \beta_i' x_{ijs} + \varepsilon_{ijs} \qquad (1)$$

Where u_{ijs} is the utility derived by farmer *i* choosing alternative j in choice task *s*, x_{ijs} is a vector of observable attributes, β_i is a vector of estimated parameters and ε_{ijs} is the random error component of the model. The error terms are assumed to be independent and identically distributed with a Gumbel distribution, which captures variations in preferences and errors in individuals' perceptions.

Since I cannot directly observe the vector of utilities for each individual, I observe the sequence of choices that the individual makes, and estimate the conditional probability of this observed sequence as follows:

$$P\left(y_i \middle| x_{i1s}, x_{i2s}, \dots, x_{ijs}, \varphi\right) = \int \frac{\exp\left(\beta_i' x_{iy_{is}s}\right)}{\sum_k \exp(\beta_i' x_{iks})} f(\beta|\varphi) d\beta \tag{2}$$

Equation 2 represents a random parameter logit model (RPL). In it I assume that producers' preferences for different farming management systems are heterogeneous, or in other words, that not every farmer has the same preference. This model is used to allow a random preference variation, it relaxes the limitation of a traditional logit model by allowing these random preferences to come from a sample with a specified distribution (McFadden and Train, 2000). Allowing for free correlation of the random parameters in the RPL model also allows us to study the preference relationship between attributes. For the analysis in this study, I let the coefficients corresponding to each attribute to take a normal distribution to allow for both positive and negative preferences for each of the attributes.

Individual coefficients estimated in the random parameter logit model have limited economic interpretation due to the non-cardinal nature of utility. However, attribute trade-offs can be calculated using a relative combination of selected coefficients from this model to provide meaningful insights into producer behavior. I follow Nahuelhual et al. (2004) and Rigby and Burton (2005) to estimate how willing are producers to change their production practices.

$$WTC = \frac{MU}{MUI} \qquad (3)$$

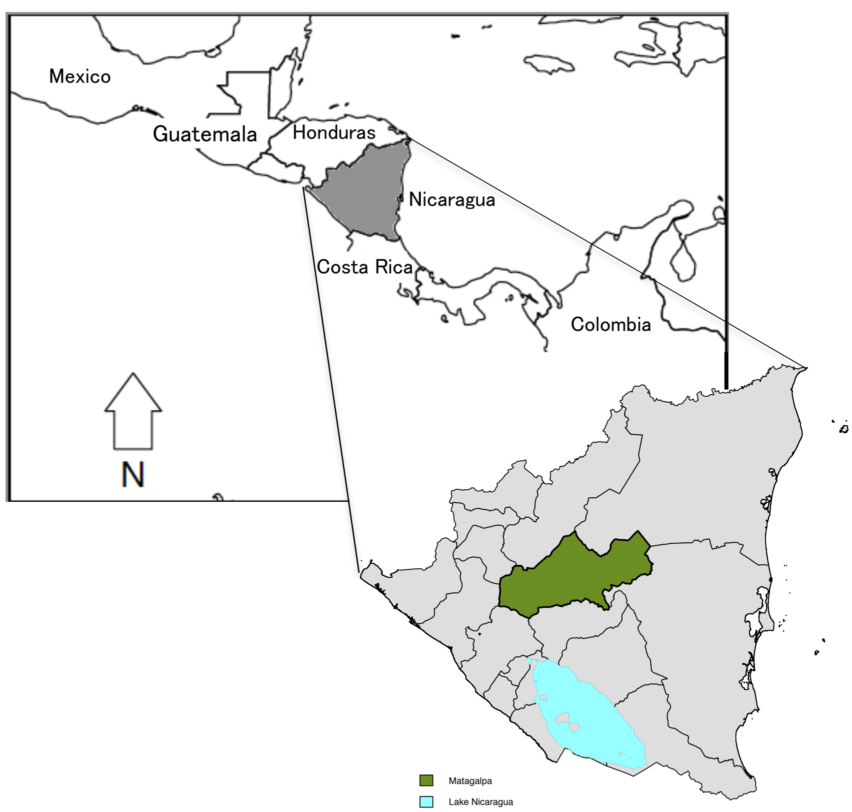
where MU is the marginal utility of the various production attributes and MUI is the marginal utility of profit, which is proxied with the premium/discount coefficient. The term willingness to change (WTC) captures both the willingness to pay (WTP) and the willingness to accept (WTA) terms. A negative WTC reflects a premium that producers would have to receive to change their behavior, and a positive WTC reflects a discount that they are willing to accept when providing a given attribute.

Data and Choice Experiment Design

Data and Sample Characteristics

Data for this research were collected in the department of Matagalpa in northern Nicaragua between June and July 2015 using a two stage stratified random sample of 236 coffee producing households. First, communities in Matagalpa were stratified by level of vulnerability to climate change. Vulnerability was determined by the average elevation in which the community was located. Higher elevation (above 1000 meters above sea level) had a lower vulnerability index than those at lower elevations, as coffee-growing households in higher elevations will be less affected by increased temperatures. In this first stage, a random sample of communities was selected based on their vulnerability index score. In the second stage, households in each of the selected communities were drawn from a census of coffee producers in the region. The households surveyed in this study form part of an ongoing project on climate change and food security conducted by the International Center for Tropical Agriculture (CIAT). After eliminating households for which data were missing or incomplete, the data set for this analysis was reduced to 221 households in the department of Matagalpa, with 9 out 13 municipalities being represented; municipalities not sampled were in regions of Matagalpa where coffee is not grown. A map of the study area is presented in Figure 9

Figure 9. Map of Study Area



Household surveys enable us to collect information on demographic and socio-economic characteristics, agricultural production, and experiences with economic and climatic shocks. These additional sources of information help us to understand the preference heterogeneity of survey respondents, and to examine the determinants of farmer preferences and behavior. Table 6 summarizes some of the characteristics of the producers in the sample. The average age of the respondents is 46 years with an average of 3.8 years of formal education completed. The mean area under production is 4.8 hectares and the mean annual coffee production is 9.7 quintales of wet parchment[4] (312.8kg) per hectare. Forty-six percent of the sample are members of a coffee cooperative and 65% are male-headed households. Among study households, 30.9% and 32.2% of have access to subsidized pesticides and fertilizers respectively, while only 38.5% of farmers report having had access to on-farm extension services in the year prior to data collection. The majority of farmers grow only one variety of coffee (Catimor) (59.8%) and 45.7% of farmers intercropped their coffee with two additional shade crops (banana and citrus trees).

[4] Wet parchment is a state of the coffee in its transformation from cherry to bean. After harvesting the freshly harvested cherries are passed through a pulping machine to separate the skin and pulp from the bean. After depulping, the bean is transported to water-filled tanks for fermentation where they remain from 12 to 48 hours. When fermentation is complete, the beans are rinsed and are ready for drying. Coffee at this stage of the wet milling process is known as wet parchment.

Table 7. Sample Characteristics

Variable	Means (% where noted)	
Male	65.4%	
Age	46.4	(15.28)
Household Size	5.4	(2.12)
Years of Education	3.8	(3.48)
Years in Coffee	16.5	(12.48)
Total Coffee Income (USD) per ha	821.8	(875.11)
Total income (USD)	5,648.3	(7,377.11)
Total area under coffee production (ha)	4.8	(5.38)
Total Coffee Production (quintales[1]) per ha	9.7	(120.59)
Cooperative membership	45.5%	
Access to Pesticides	30.9%	
Access to Fertilizers	32.2%	
Extension Services	38.5%	
Farms with 1 variety of coffee	59.8%	
Farms with 2 varieties of coffee	32.7%	
Farms with 1 additional shade crop	18.2%	
Farms with 2 additional shade crop	45.7%	

[1] *1 Quintal= 46kg; Standard deviations are presented in parentheses*

Choice Experiment

The choice experiment in this study was designed to compare the producers' management of their current coffee field to other hypothetical coffee fields. To make this comparison, information about their farm characteristics were collected during the implementation of the survey.

To identify relevant coffee production attributes, interviews with key informants and coffee producers were carried out in March and April 2015. Six attributes were selected to for inclusion in the choice experiment: input provision, access to extension services, labor requirements, coffee diversification, crop diversification, and income generated from the farm. These attributes are reviewed below.

Input Provision. Unless coffee production is profitable for farmers, they will not invest in their farms. Input constraints, such as lack of access or high costs, induce farmers to adjust their preferences for characteristics associated with their production (Wale et al., 2005). From preliminary interviews with farmers, I learned that the cost of commercial inputs (notably fertilizers and pesticides) is a high barrier to their adoption, and that most rely on the distribution of these from organizations in their region. Many studies assert that unless inputs are subsidized, farmers with income constraints will not use them (Duflo et al., 2011; Dugger, 2007). A recent study of smallholder coffee producers in Rwanda highlights this issue, where 71% and 45% of households surveyed cited low and unstable cherry prices, respectively, as their main barrier to investment in their coffee (Clay et al., 2016). In the same study, the majority of farmers who did not apply any inputs stated that a lack of access to free or subsidized inputs was their main reason for non-use. It is clear that access to inputs plays an important role in farmers' on-farm investment decisions; in this study I test how highly farmers value this access. Four levels of input distribution are specified in the choice experiment: No access to subsidized inputs, access to subsidized pesticides only, access to subsidized fertilizers only, and access to subsidized pesticides and fertilizer.

Access to Extension Services. Extension services have the potential to influence farmers' decisions to change their production practices in response to climate change (Maddison, 2007). Indeed, a lack of training and information was an issue frequently raised by coffee producers during the piloting period of the study. Farmers expressed a deep dissatisfaction with the low level of on-farm support provided by government agencies and by their own cooperatives, especially during and after the devastating leaf rust outbreak. These services were included as a binary variable that captured whether the field received on-farm extension services.

Labor Requirements. Similarly, practices that require high levels of labor investments need to be considered in this study. Maintaining proper shade in farms, mulching, and pruning all are labor labor-intensive practices, and while better-endowed coffee producers may be able to overcome some of these labor requirements by hiring outside labor, smallholder producers mostly rely on household labor for these tasks. Two levels of labor requirement are used: high and low, which correspond to a 50% increase/decrease of their current person-day requirements.

Coffee Diversification. The importance of coffee diversification derives from two main factors. On the one hand, farmers can adopt varieties that are resistant to droughts and higher temperatures to cope with the impacts of climate change, and on the other hand, new varieties of coffee are being developed that keep the quality of Arabica varieties but take the physical attributes of lower quality coffee varieties. Two levels were included in this attribute, corresponding to the establishment of one or two coffee varieties in the field.

Crop Diversification. The incorporation of shade into coffee fields cannot be overstated. As reviewed earlier in this article, shade helps to protect biodiversity and soils, lowers farm temperatures, and provides alternative food sources. Shade crops can also expand the income potential of the farm and help to retain water in the soils. Four levels were included in this attribute corresponding to a field containing coffee alone, coffee plus one additional shade crops, coffee plus two additional shade crops, and coffee plus three additional shade crops. The additional crops that were used as examples in the choice experiment were identified from the climate change literature that looks at successful coffee crop pairings, and they are banana, citrus, and cacao.

Income. Finally, an additional parameter capturing the percentage change in income generated from coffee fields was included to help estimate farmers' willingness to change. Four levels were included and correspond to a 25% and 50% increase or decrease in income generated from their coffee fields. A percentage specification was used since it is difficult to estimate the exact income generated from a field due to differences in cropping intensities, farm sizes, and productivity levels.

Detailed information on the selected attributes and their levels is presented in Table 8.

Table 8. Coffee Production Attributes Used in Choice Experiments

Attribute	Levels	Definition
Input Provision	None, Pesticides only, Fertilizer only, Pesticide and fertilizers together	Producer access to subsidized inputs.
Extension Services	Yes, No	Producer access to on farm extension services.

Table 8 (Cont'd)

Labor Requirements	High, Low	Labor requirement defined as a 50% increase in labor (high) or a 50% decrease in labor (low).
Coffee Diversification	1 variety, 2 varieties	The number of established coffee varieties.
Crop Diversification	1 (sole coffee), 2 (coffee and banana, coffee and citrus, coffee and cacao), 3 (coffee and banana/citrus, coffee and banana/cacao, coffee and citrus/cacao), 4 (coffee and banana/citrus/cacao)	Total number of crops established with the coffee.
Income	-50%, -25%, +25%, +50%	Percentage change of expected coffee income relative to the farmer's coffee income for the previous year.

Given the above attribute selection, the econometric specification of the choice experiment takes the following functional form:

$$u_{ijs} = \beta_{i1}Inputs_{ijs} + \beta_{i2}Extension_{ijs} + \beta_{i3}Labor_{ijs} + \beta_{i4}CoffeeD_{ijs} + \beta_{i5}CropD_{ijs} + \beta_{i1}Income_{ijs} + \varepsilon_{ijs} \quad (4)$$

Where u_{ijs} is the utility derived from mapping the coffee farming system into utility space, $Input_{ijs}$ is the level of input subsidy, $Extension_{ijs}$ is a binary extension service provision, $Labor_{ijs}$ is a binary for labor requirement, $CoffeeD_{ijs}$ is a binary variable for coffee diversification, $CropD_{ijs}$ is the level of crop diversification, and $Income_{ijs}$ is the level of income change. The indices *i, j*, and *s*, represent the individual, the choice alternative, and the choice set, respectively; and β is the coefficient associated with each attribute preference.

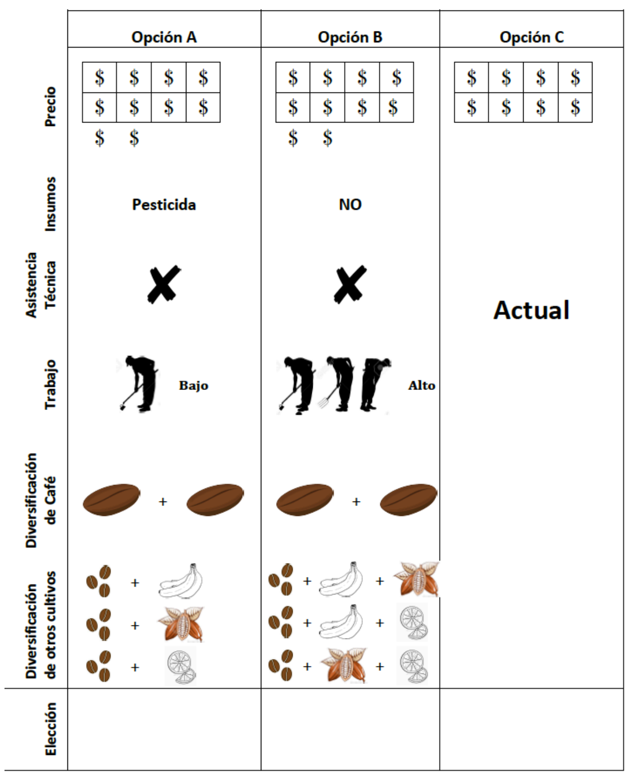
Following the selection of the attributes, a pretest was conducted in early June 2015 to test the comprehension and suitability of choice experiment parameters.

A D-optimal design (one which optimizes the model fit while minimizing the covariance of the parameter estimates) with null priors was used for the choice experiment.[5] The design resulted in three choice tasks which were blocked into six groups to help alleviate response fatigue. Each coffee producer was presented with five different choice tasks consisting of two alternative coffee farming operations containing the study attributes. A third alternative included in the design allowed the respondents to opt-out of the hypothetical scenarios and choose to continue producing coffee under their current management practices, defined as the "status-quo option." Data for this alternative were collected as part of the household questionnaire. To avoid issues of comprehension and to accommodate different levels of farmer literacy, the choice sets were illustrated and presented to producers on laminated cards.

[5] Null priors were used in the design due to a lack of information on farmer valuations of the attributes selected, as well as time and logistical constraints associated with conducting a representative pilot study.

After gathering information from the farmers about their current production practices and farm characteristics (status quo), enumerators introduced the choice experiment to the respondents and asked them to answer the following question: "*Considering the current amount of land that you dedicate to coffee production, would you be willing to change that land to one that takes the following characteristics?*" at this point, farmers were presented the laminated card depicting the choice sets and each option was explained. An example of a choice set is presented in Figure 10.

Figure 10. Example of Choice Set



Results and Discussion

Maximum likelihood estimates for a random parameter logit model are presented in Table 9. The significant standard deviation coefficients in Table 8 in the RPL indicate that coffee farmers have heterogeneous preferences with respect to the production practices, and do not derive the same level utility from the same attributes.

The following conclusions are presented in terms of the utility that these choices generate for the respondents. Utility is here defined as the value or the satisfaction that a producer gains from the attributes in the choice experiment. I find that pesticide provision has a negative effect on utility for farmers in Matagalpa, but that when it is provided together with fertilizer the effect on utility is positive and significant, as is the provision of fertilizer alone. I also find that extension services have a positive and significant utility for farmers and that labor requirements have a negative and significant effect on utility. I did not find a significant effect on utility from the diversification of their fields with alternative coffee varieties or crops. However, as seen in the distribution of the standard deviations, the preferences on crop and coffee diversification are heterogeneous in the sample, confirming the hypothesis that preferences are not homogenous across coffee producers in the region. I also find evidence of preference heterogeneity (significant standard error coefficients) regarding input subsidies, extension services, and labor requirements.

Table 9. Parameter Estimates from a Random Parameter Logit Model

	Coefficient	Std. Error
Random parameter means		
Income	0.031	0.003***
Pesticide	-0.632	0.146***
Fertilizer	0.300	0.126***
Pesticide/Fertilizer	0.800	0.130***
Extension	0.422	0.187***
Labor	-0.002	0.001**
Coffee Div.	0.169	0.158
Crop Div.	-0.114	0.067**
Random parameter standard deviations		
Income	0.021	0.003***
Pesticide	0.383	0.219**
Fertilizer	0.078	0.250
Pesticide/Fertilizer	0.036	0.257
Extension	1.465	0.296***
Labor	0.003	0.003
Coffee Div.	1.028	0.257***
Crop Div.	0.513	0.084***
N	1,100	
Log-Likelihood	-891.9	
Adjusted Pesudo R-Squared	0.262	
AIC	1,872	

*Standard errors are provided for each coefficient: *, **, *** denotes statistical significance at the 0.10, 0.05, and 0.01 levels, respectively. Income represents the profit variable, Pesticide, Fertilizer, and Pesticide/Fertilizer are binary variables indicating access to subsidized pesticides, fertilizers, and pesticides and fertilizers, respectively, Extension is a binary variable indicating access to on farm extension services, Labor is a binary variable that indicates high or low labor requirements, Coffee Div. is a binary variable that indicates the presence of 1 or 2 coffee varieties, and Crop Div. indicates level of crop diversity richness.*

Allowing for free correlation of the random parameters in the RPL model allows us to interpret their correlations. The correlation matrix presented in Table 9 shows a significant correlation between income and coffee diversification (0.45), income and pesticide subsidies (0.59), and income and labor (0.84), implying that farmers who value coffee diversification, pesticide provision, and higher labor investments are also motivated by higher returns from their farms. Similarly, I find that access to fertilizer and access to fertilizers and pesticides together are negatively correlated with income (-0.54 and -0.57 respectively). There was no significant correlation between income and extension services, and income and crop diversification. Although correlation does not ensure causality, I can attempt to explain some of these relationships. For example, it is likely that lower farm income as a result of low yields leads farmers to place greater value on the provision of yield-boosting fertilizers. Similarly, farmers with higher incomes appear to be more likely to value the work from paid labor.

Table 10. Cholesky and Correlation Matrix for RPL Model

Cholesky Matrix								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income (1)	0.287							
Pesticide (2)	0.022	1.018						
Fertilizer (3)	-0.011	-0.849	0.301					
Pesticide/Fertilizer (4)	-0.017	-0.959	0.330	0.302				
Extension (5)	-0.006	-1.145	0.873	-0.176	0.177			
Labor (6)	0.000	0.007	-0.004	-0.005	0.001	0.001		
Coffee Div. (7)	0.017	1.230	-0.596	-0.779	-0.885	0.004	0.310	
Crop Div. (8)	-0.002	0.193	-0.101	-0.106	-0.126	0.000	-0.199	0.253

Correlation Matrix								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income (1)	1							
Pesticide (2)	0.599	1						
Fertilizer (3)	-0.541	-0.912	1					
Pesticide/Fertilizer (4)	-0.571	-0.749	0.447	1				
Extension (5)	-0.012	-0.548	0.725	-0.106	1			
Labor (6)	0.837	0.560	-0.576	-0.569	0.083	1		
Coffee Div. (7)	0.427	0.681	-0.572	-0.544	-0.379	0.287	1	
Crop Div. (8)	-0.084	0.242	-0.221	-0.168	-0.122	-0.049	-0.223	1

The derived WTC estimates, presented in Table 10, put these results in a context that is easier to interpret. A negative WTC coefficient represents the income premium that farmers would need to receive to make a change, while a positive WTC coefficient represents how much income a farmer would be willing to give up to receive a good or service. Non-significant coefficients represents changes that farmers are willing to make without needing any incentives.

Table 11. Willingness to Change Estimates

Attribute	Mean	Confidence Interval
Pesticide	-27.93	[-35.43, 0.75]
Fertilizer	13.33	[-2.64, 17.35]
Pesticide/Fertilizer	35.66	[19.31, 35.88]
Extension	21.87	[-18.79, 34.59]
Labor	-0.10	[-0.14, -0.08]
Coffee Div.	4.25	[-9.82, 58.78]
Crop Div.	-5.19	[-8.86, 3.81]

Pesticide, Fertilizer, and Pesticide/Fertilizer are binary variables indicating access to subsidized pesticides, fertilizers, and pesticides and fertilizers, respectively, Extension is a binary variable indicating access to on farm extension services, Labor is a binary variable that indicates high or low labor requirements, Coffee Div. is a binary variable that indicates the presence of 1 or 2 coffee varieties, and Crop Div. indicates level of crop diversity richness.

Our model results reveal that coffee producers from Matagalpa require a premium of 42.65USD per hectare of coffee (5.19% of their annual coffee income) to introduce an additional shade crop into their coffee fields, but they are willing to accept a 34.9USD discount (per hectare of coffee) to introduce an additional coffee variety in their fields. These results suggest that while farmers are willing to give up part of their income to adopt new coffee varieties in their fields, they would require a premium before introducing an additional shade crop into their fields.

These results are consistent with observations made by the researchers in the field, where they note farmers actively seeking out newer coffee varieties resistant to the leaf rust pest, which suffered a major outbreak in the region 2012 and farmers reported yield losses of up to 60 percent. Leaf rust attacks mostly Arabica varieties and farmers have been systematically uprooting their Arabica coffee and replacing them with varieties of coffee that are resistant to the leaf rust. These big losses, compounded with recent droughts that have impacted food crops (bean and maize), have meant that farmers have been looking for coping mechanisms that help to mitigate some of these shocks (income loss from coffee failures, and food loss from droughts). Included in this coping strategy is the establishment of varieties of coffee resistant to the leaf rust, the Catimor coffee tree is the most commonly cited hybrid variety that farmers are planting.

Why do farmers require a premium to establish new shade trees? It is commonly assumed that shaded plantations are less profitable, but this is an assumption that is often based on incomplete cost-benefit data. For the most part, the productivity of coffee is used as an indicator for profitability, which is assumed to be lower for shaded coffee fields. These calculations, however, do not account for the different costs of production, the quality differential, nor for the direct and indirect benefits that shaded trees provide. (Jezeer and Verweij, 2015). Although many farmers in the sample express that they liked having additional crop trees in their coffee fields, they mostly spoke of only needing a handful of these trees, and do not wish to have a coffee system with managed shade, which would optimize their field (economically and/or environmentally).

I find that farmers are willing to accept a 179.7USD discount per hectare of coffee in order to have access to on farm extension services. This brings to light how important these services are for smallholder farmers. Extension services can play a pivotal role in helping farmers build adaptive capacity to climate change by holding trainings, providing on-farm recommendations, and by sharing information about markets (Agrawal and Perrin, 2009). Additionally, many farmers rely on these services for recommendations on farm management and to learn about climatic and market forecasts. Farmers in the sample require a premium of 8.21USD per person per day before they will double their labor dedicated to coffee. Smallholder producers often rely on their household labor to manage their farms; in Nicaragua, hired labor for coffee production is very common (Valkila and Nygreen, 2010). Unless coffee farms yield higher returns households may choose to sell their labor instead of investing it in their own farms.

Finally, regarding the provision of inputs, I find that farmers are willing to accept 110USD and 293USD discounts in exchange for subsidized fertilizers and fertilizers and pesticides together respectively. Yet, they would require a premium of 229USD to accept pesticides provided through a subsidy. The premium associated with subsidized pesticides can be explained by the failure of organizations to adequately respond to the leaf rust epidemic. A large segment of farmers in this study expressed their discontent with the effectiveness of the pesticides provided by private and public extension officers; they experienced even greater coffee losses when they applied pesticides that were ineffective at treating leaf rust, because their coffee trees became even weaker and were still vulnerable to the rust., in some cases with complete crop failures. Following a season of devastating losses, many farmers in the sample pulled out their coffee trees (Arabica variety) and replaced them with hybrid varieties that they believed would be more resistant to leaf rust. This premium for pesticides suggests that farmers are seeking compensation for yield losses in previous years induced by the failures of proper pesticides to prevent the treatment and the spread of the leaf rust.

Although farmers indicate they would need a premium to accept pesticides, this effect is erased when pesticides are offered together with fertilizers. Fertilizers play an important role in the production cycle of the coffee tree as they, together with other practices (such as pruning), help with the healthy development of the fruit (Van der Vossen, 2005).

Conclusions

The earth's climate is changing at an alarming rate, and these changes will not only result in biodiversity loss but will also have dire consequences for the livelihoods of people around the world (Cardinale *et al*., 2012). In particular, these changes have a direct impact on the livelihoods of rural coffee producing households, many of which will surely witness a future decline in the suitability of their agroecology for coffee production, and will experience additional shocks to their food security and wellbeing as a result of these climatic events. Expediency is needed in responding to these impacts by protecting and improving the conditions under which biodiversity can flourish.

How farmers in Nicaragua will adapt to climate driven changes in the country's suitability for coffee production, is a top priority for policy-makers. This study provides an innovative approach to studying the incentives of coffee farmers to adopt practices that will help them to build adaptive capacity in response to these changes. Discrete choice experiments are used to examine farmers' preferences for crop diversification in coffee farming systems, and to estimate these preferences using a random parameter model that captures the heterogeneity of farmer preferences at the individual level.

Unless farmers value the services that shade grown coffee provides they will be unwilling to incorporate it into their farms. I find that farmers in Nicaragua would need a premium to add additional shade to their farms, so an important question to explore in future research is how and for what reasons farmers value the services that shade provides? Do they value it for the ecosystem services that they provide or do they value its potential for alternative sources of food and income? In this research, we explore the benefits of shade in light of its potential to help farmers become more resilient to climate change, yet, we know that there are other benefits that shade trees can provide, giving farmers other reasons for choosing to use shade, and understanding the benefits that shade provides to the farmers an important question to explore.

The devastating impacts of leaf rust in Nicaragua and the rest of Central America have led farmers to respond in unexpected ways. Farmers are not willing to give up income to have access to subsidized pesticides from the government or other stakeholders in the coffee value chain. To the contrary, they require a price premium before they will accept such subsidies. This speaks to potential issues of trust between farmers and organizations supporting farmers in Nicaragua. Coffee producers expressed frustration and mistrust of organizations that were not able to properly support them when the rust outbreak occurred. Climate change science is a somewhat new field of study, and adaptation to climate change an emerging field of research. There is no doubt that the path towards adaptive capacity will be marked with false starts, and as new interventions are introduced organizations must take into consideration the possibility of failure and be transparent with farmers about the inherent risks of such failure.

An important area for future research lies in the question of how relationships are built and where markets and organizations are failing farmers when they experience natural shocks, such as pest and disease outbreaks or extended periods of drought. This research will be particularly germane given the likelihood that such shocks will occur at higher rates and with potentially higher intensities as the grip of climate changes tightens. To prepare for these events, all stakeholders in the coffee sector, and beyond, need to understand how and when farmers react to these shocks and how to build effective pathways for their solution.

This study also highlights the need for support and collaboration among coffee sector stakeholders and other groups that wish to promote biodiversity conservation and environmental sustainability. Stakeholders in both groups must heed coffee producers' call and understand that unless farmers have the proper incentives to invest in production practices that will conserve the ecological integrity of coffee fields (through shade and other practices), they will make decisions based entirely on the financial utility of their coffee plantations, which often means intensifying their production by increasing the use of chemical inputs and monocultural production, or in the worst case scenario, abandon their coffee fields altogether.

Study findings also demonstrate that there is significant heterogeneity of preferences amongst farmers, and organizations that wish to help farmers build adaptive capacity to climate change, while also promoting biodiversity conservation, must take this into consideration when designing interventions that promote crop diversification, and measures that help farmers build adaptive capacity to climate change.

Although I employ in this research a quantitative method for studying producers' preferences for crop diversification, I recognize that a qualitative approach to understanding the implicit tradeoffs involved in the decisions farmers make, as well as the barriers and contexts in which they make those decisions, is needed to confirm and validate the initial interpretations of the data. Additionally, providing tools to enhance farmers' understanding of the ecological complexity of shaded coffee fields and the diverse ecosystem services that they provide may prove to be useful for researchers and practitioners committed to incentivizing coffee farmers to adopt practices that will promote greater sustainability in the sector.

The livelihoods of hundreds of thousands of coffee producers around the world are at risk due to the threat climate change poses to the suitability of coffee producing regions to continue to grow coffee. At the same time, biodiversity richness is decreasing in coffee regions that are transitioning towards more intensive production. While this study provides new insights into how coffee producers value key attributes related to coffee production in Nicaragua, this approach and the insights from this study can be easily adapted for use in other coffee growing regions of the world and even to other crops, such as cacao, which grown under similar agro-ecological conditions.

REFERENCES

REFERENCES

Agrawal, Arun, and Nicolas Perrin. "Climate adaptation, local institutions and rural livelihoods." *Adapting to climate change: thresholds, values, governance* (2009): 350-367.

Armbrecht, Inge, Ivette Perfecto, and John Vandermeer. "Enigmatic biodiversity correlations: ant diversity responds to diverse resources." Science 304.5668 (2004): 284-286.

Avelino, Jacques, et al. "The coffee rust crises in Colombia and Central America (2008–2013): impacts, plausible causes and proposed solutions."*Food Security* 7.2 (2015): 303-321.

Baca, María, Peter Läderach, Jeremy Haggar, Götz Schroth, and Oriana Ovalle. "An integrated framework for assessing vulnerability to climate change and developing adaptation strategies for coffee growing families in Mesoamerica." *PloS one* 9, no. 2 (2014): e88463.

Bennett, Jeff, and Ekin Birol, eds. *Choice experiments in developing countries: Implementation, challenges and policy implications*. Cheltenham: Edward Elgar, 2010.

Birol, Ekin, Eric Rayn Villalba, and Melinda Smale. "Farmer preferences for milpa diversity and genetically modified maize in Mexico: a latent class approach." *Environment and Development Economics* 14.04 (2009): 521-540.

Borrero H, José Ignacio. "La substitución de cafetales de sombrío por caturrales y su efecto negativo sobre la fauna de vertebrados." Caldasia(1986): 725-732.

Cardinale, Bradley J., et al. "Biodiversity loss and its impact on humanity."*Nature* 486.7401 (2012): 59-67.

Cressey, Daniel. "Coffee rust regains foothold." *Nature* 493.7434 (2013): 587.

Duflo, Esther, Michael Kremer, and Jonathan Robinson. "Nudging farmers to use fertilizer: Theory and experimental evidence from Kenya." *The American Economic Review* 101.6 (2011): 2350-2390.

Dugger, Celia W. "Ending famine, simply by ignoring the experts." *New York Times* 2.12 (2007): 07.

Feder, Gershon, Richard E. Just, and David Zilberman. "Adoption of agricultural innovations in developing countries: A survey." *Economic development and cultural change* (1985): 255-298.

Hernandez, Sonia M., et al. "Coffee agroforests remain beneficial for Neotropical bird community conservation across seasons." *PloS one* 8.9 (2013): e65101.

Jezeer, Rosalien, and Pita Verweij. "SHADE-GROWN COFFEE." (2015).

Laderach, Peter, Jeremy Haggar, Charlotte Lau, Anton Eitzinger, Oriana Ovalle, María Baca, Andy Jarvis, and Mark Lundry. "Mesoamerican coffee: building a climate change adaptation strategy." (2013).

Laderach, Peter, Mark Lundy, Andy Jarvis, Julian Ramirez, Emiliano Perez Portilla, Kathleen Schepp, and Anton Eitzinger. "Predicted impact of climate change on coffee supply chains." In *The Economic, Social and Political Elements of Climate Change*, pp. 703-723. Springer Berlin Heidelberg, 2011.

Lancaster, Kelvin J. "A new approach to consumer theory." *The journal of political economy* (1966): 132-157.

Maddison, David J. "The perception of and adaptation to climate change in Africa." *World Bank Policy Research Working Paper* 4308 (2007).

McFadden, Daniel, and Kenneth Train. "Mixed MNL models for discrete response." *Journal of applied Econometrics* 15, no. 5 (2000): 447-470.

Mendez, V. Ernesto, et al. "Agrobiodiversity and Shade Coffee Smallholder Livelihoods: A Review and Synthesis of Ten Years of Research in Central America*." *The Professional Geographer* 62.3 (2010): 357-376.

Murrieta-Galindo, Rene, et al. "Coffee agrosystems: an important refuge for amphibians in central Veracruz, Mexico." *Agroforestry systems* 87.4 (2013): 767-779.

Nahuelhual, Laura, Maria L. Loureiro, and John Loomis. "Using random parameters to account for heterogeneous preferences in contingent valuation of public open space." *Journal of Agricultural and Resource Economics* (2004): 537-552.

Ortega D.L., Waldman K.B., Richardson R.B., Clay D.C., Snapp S.S., Sustainable Intensification and Farmer Preferences for Crop System Attributes: Evidence from Malawi's Central and Southern Regions". *World Development* (2016)

Ovalle-Rivera, Oriana, Peter Läderach, Christian Bunn, Michael Obersteiner, and Götz Schroth. "Projected Shifts in Coffea arabica Suitability among Major Global Producing Regions Due to Climate Change." (2015): e0124155.

Perfecto, Ivette, and John Vandermeer. Coffee Agroecology: A new approach to understanding agricultural biodiversity, ecosystem services and sustainable development. Routledge, 2015.

Perfecto, Ivette, Armbrecht, I., Philpott, S. M., Soto-Pinto, L., & Dietsch, T. V. "Shaded coffee and the stability of rainforest margins in northern Latin America." *Stability of Tropical Rainforest Margins*. Springer Berlin Heidelberg, 2007. 225-261.

Perfecto, Ivette, John Vandermeer, and Angus Wright. Nature's matrix: linking agriculture, conservation and food sovereignty. Earthscan, 2009.

Ponte, Stefano. "The latte revolution'? Regulation, markets and consumption in the global coffee chain." *World development* 30, no. 7 (2002): 1099-1122.

Rigby, Dan, and Michael Burton. "Preference heterogeneity and GM food in the UK." *European Review of Agricultural Economics* 32, no. 2 (2005): 269-288.

Saldaña-Vázquez, Romeo A., et al. "Population composition and ectoparasite prevalence on bats (Sturnira ludovici; Phyllostomidae) in forest fragments and coffee plantations of central Veracruz, Mexico." *Biotropica* 45.3 (2013): 351-356.

Tittonell, Pablo, and Ken E. Giller. "When yield gaps are poverty traps: the paradigm of ecological intensification in African smallholder agriculture." *Field Crops Research* 143 (2013): 76-90.

Valkila, Joni, and Anja Nygren. "Impacts of Fair Trade certification on coffee farmers, cooperatives, and laborers in Nicaragua." *Agriculture and Human Values* 27.3 (2010): 321-333.

Valkila, Joni. "Fair Trade organic coffee production in Nicaragua—Sustainable development or a poverty trap?." *Ecological Economics* 68.12 (2009): 3018-3025.

van Rikxoort, Henk, Götz Schroth, Peter Läderach, and Beatriz Rodríguez-Sánchez. "Carbon footprints and carbon stocks reveal climate-friendly coffee production." *Agronomy for Sustainable Development* (2014): 1-11.

Van der Vossen, H. A. M. "A critical analysis of the agronomic and economic sustainability of organic coffee production." *Experimental agriculture* 41.04 (2005): 449-473.

Vermeulen, Sonja J., et al. "Addressing uncertainty in adaptation planning for agriculture." *Proceedings of the National Academy of Sciences* 110.21 (2013): 8357-8362.

Wale, Edilegnaw, et al. "Economic analysis of farmers' preferences for coffee variety attributes: lessons for on-farm conservation and variety adoption in Ethiopia." *Quarterly Journal of International Agriculture* 44.2 (2005): 121-140.

Chapter 4: Determinants of Adoption of Sustainable Production Practices among Smallholder Coffee Producers in Nicaragua

Introduction

Efforts to slow down and eventually reverse the trend of climate change will take time, and in some cases, the negative impacts of climate change will be felt long before long-term solutions to this problem can bear fruit. Adaptation and mitigation strategies constitute the front line of attack for rural households in developing countries that rely on agricultural production and natural resource use as their main source of income and growth, and whose livelihoods are threatened by climate change. Amongst these strategies, the adoption of sustainable and climate smart production practices have been identified as critical for smallholder producers, but it is uncertain just how they should be promoted (Laderach *et al*., 2013). Agricultural organizations and cooperatives have a long history in promoting the adoption of new technologies and practices among smallholder producers and could potentially play a sizable role in helping farmers to build better adaptive capacity, yet further research is needed to understand how and the degree to which they contribute to specific adaptation and mitigation strategies for climate change.

The impacts of climate change will become more severe with time; regions of the world that have already experienced periods of seasonal droughts will see a rise in the frequency of these droughts. Similarly, some areas will experience severe flooding due to increased rainfall occurrence. And changes in global temperatures will also result in certain areas becoming no longer suitable for agricultural production (Fischer et al., 2002). Perhaps no population is more vulnerable to the consequences of these changes than poor agrarian households that depend on crop production to make a living. As the intensity and frequency of these events increase, households can experience loss of assets (such as household assets, crops, access to water, and loss of health) and are left with less time to recover from the previous shocks, resulting in severe food insecurity (Laderach et al., 2013; Vermeulen et al., 2012; Fischer et al., 2002). Given the vulnerability of smallholder farmers to climate change, there is growing consensus that the research and development on adaptation strategies will become increasingly needed (van Rikxoort *et al.,* 2014), and that farmer adoption of sustainable, mitigating technologies and practices constitute one of the critical pieces to a longer-term solution (Nelson *et al*., 2009). Included in their mitigation strategies is how they perceive and use collective organization and action as a vehicle for their response.

Smallholder farmers are also facing sizable challenges and barriers to entering profitable markets. Amongst these barriers are costs associated with poor physical infrastructure, such as a lack of roads or transportation networks, a lack of market and pricing information, poor access to inputs, and little access to technical support and training (Barrett, 2008). Cooperatives can help smallholders to overcome some of these barriers and are widely recognized in agricultural markets as an effective mechanism that brings together smallholder producers who wish to work together to overcome some of the costs associated with market participation. In addition, cooperatives have better bargaining power and can extract more favorable terms of trade from downstream buyers (Barrett, 2008). Cooperatives help farmers not only by increasing productivity but they can also add value to agricultural products through processing. This is particularly true in the coffee industry where coffee processing facilities are cooperatively owned and operated.

Investments in and adoption of improved technologies and production practices by smallholder producers require significant support and investment from the public and private sectors (Barrett, 2008). At no time is this support more critical than when smallholder farmers experience low yields, high production costs, relatively high labor requirements for production, and face unstable prices for their agricultural products (Donovan and Poole, 2014), all of which are likely to be exacerbated by climate change. In many instances, the formation of agricultural cooperatives have been successful in helping smallholders farmers to overcome many of these barriers through the dissemination of inputs, loans, and training opportunities (Abebaw and Haile, 2013), and can play an important role in helping farmers to transition towards production practices that will help them build adaptive capacity against the impacts of climate change.

In a study of agricultural cooperatives in Ethiopia, Abebaw and Haile (2013) find that cooperatives membership has a strong and positive effect on the adoption of fertilizers and that their members have better access to extension services. Cooperatives can also play an important role in providing financial incentives to adopt new technologies; in a study by (Mounir *et al.*, 2016) the authors find that incentives in the form of payments for agricultural-environmental services can increase the adoption of improved technologies. Climate change and increasing environmental pressures are pushing demand for alternative management approaches (Virapongse *et al.,* 2016). Wollni and Zeller (2007) find that cooperative membership has a positive impact in income and the adoption of specialty coffee varieties amongst coffee producers in Costa Rica. Wollni *et al*. (2010) also find that smallholder farmers in Honduras who participated in cooperatives were more likely to have adopted a higher number of soil conservation practices than farmers who did not belong to cooperatives. They conclude that in addition to all the technical support that cooperatives offer their members, they are also important in increasing the odds of adoption of sustainable soil management practices. Other studies have also found that cooperative membership is a significant determinant of farmer adoption of technologies and improved production practices (Verhofstadt and Maertens, 2014a; Fischer and Qaim, 2012). Another set of studies have found that farmers who belong to farmers' associations or cooperatives are more likely to have higher incomes and receive higher prices for their products than those who do not belong (Verhofstadt and Maertens, 2014b; Jena *et al*., 2012).

Producers in regions where Arabica coffee is produced are particularly susceptible to a changing climate due to the narrow band of elevation in which Arabica coffees can be grown and the fact that it requires 3-5 years to mature and that significant investment is required to plant and maintain coffee. Moreover, coffee has long been known as a commodity product with a large "footprint" in poor, often mountainous countries in the tropics, and as a leading source of economic growth for many of them. On a global scale it is recognized as one of the most traded agricultural commodities (Ponte, 2002).

In recent decades, the productive potential of the coffee growing regions has become increasingly compromised by the impacts of climate change and is further exacerbated by the intensification of agricultural practices, a predictable consequence of a growing global demand for coffee and increasingly competitive markets, particularly for specialty coffees (Donovan and Poole, 2014). Intensification often involves unsustainable practices – such as shifting coffee plantations from polycultural to monocultural production (van Rikxoort *et al.,* 2014) and the overuse of toxic chemical inputs that can have dire consequences for the agro-ecological composition of the tropical soils (Perfecto et al., 1996 and 2007). In contrast, there are a number of sustainable practices that can help farmers become more resilient to a changing climate. Shade grown coffee production helps to protect the bio-diversity of the tropics, store carbon from the atmosphere, protect watersheds by reducing run-off, and prevent erosion. Integrated pest management (IPM) is conducive to minimizing toxic chemical use (Perfecto *et al*., 2007; Valkila, 2009). Finally, crop diversification not only helps to protect the ecological diversity of the land but also, as Mendez *et al*. (2010) find, it contributes to household livelihoods by generating products for consumption (food security) and sales (income generation).

Although there is evidence that cooperatives can play an important role in building sustainable market linkages between smallholders and intermediary firms, in reaching quality standards, and providing training and financial services to smallholder farmers (Donovan and Poole, 2014; Barrett, 2008), there are important questions that remain unanswered. In particular, whether producers associated with cooperatives are better prepared to cope with the effects of climate change is a question of notable importance that has implications for coffee sector planning and policies. And a better understanding of farmers' perceptions of climate change, their adaptation strategies, and their decision-making processes is needed to inform policies aimed at promoting successful adaptation strategies for the coffee sector.

In the present research I focus on the decision making process of farmers by studying the different practices that they have adopted on their farms. More specifically, this research aims to identify the determinants of the adoption of sustainable (adaptive to climate change) coffee production practices by producers in Nicaragua, and to examine to what extent cooperative members and non-members differ in their adoption of those practices. The hypothesis that I test in this study is that cooperative membership is a positive and significant determinant of adoption of sustainable coffee production practices.

This study contributes to the research literature by looking at the impact of cooperatives on the adoption of improved practices and technologies specifically in the Matagalpa region of Nicaragua. It addresses the research question: "does cooperative membership increase the probability of adoption of sustainable production practices in Nicaragua?" This question is not only of crucial interest to policy makers, cooperatives, and environmental agencies that wish to support the coffee sector in its struggle against the potentially devastating impacts of climate change, but also in achieving sustainable growth more generally.

Coffee in Nicaragua

In Latin America, coffee is the main source of income for more than 1 million farmers. Nicaragua alone has 48,000 farmers, 80% of which are small-scale coffee producers (Valkila, 2009). Moreover, as the largest national export, more than 30,000 smallholder farmers rely on its production as their principal livelihood (Laderach et al., 2013). Arabica coffee, the main variety cultivated in the region, needs ample and stable rainfall and a narrow interval of average temperatures (19-22°C), all of which are expected to change in coffee growing regions as their climate changes (Vermeulen et al., 2013).

Nicaragua is one of the countries in Mesoamerica that will be the hardest hit by the impacts of climate change, and all eyes are drawn to the Matagalpa coffee-growing region where the challenges facing coffee producers are known to be especially daunting (Laderach et al., 2011). How farmers there will respond to a potential 40-60% loss of agro-climatic suitability driven by a predicted 2.2ºC temperature increase and a 130mm decline in precipitation by 2050 (Ovalle-Rivera et al., 2015) is the source of much consternation and debate among industry, policy and scientific circles (Ovalle-Rivera et al., 2015; Baca et al., 2014; Laderach et al., 2013)

In a study conducted by Baca et al. (2014), the authors find that coffee farmers in Nicaragua have seen dramatic changes in rainfall patterns over the past 20 years, noting in particular the longer and hotter dry seasons and shorter and more erratic rainy seasons. The estimated income loss due to lower suitability and production is estimated at US$74.7 millions in 2050 alone (Laderach et al., 2013).

The consequences of suitability loss can be devastating to the livelihoods of smallholder producers, and research on how farmers can adapt and build resilience to the impacts of climate change is urgently needed.

Methodology and Data

This study was conducted in the department of Matagalpa in northern Nicaragua between June and July 2015. A sample of 236 households was selected using a two stage stratified random selection strategy. First, communities in Matagalpa were stratified by level of vulnerability to climate change. Vulnerability was determined by the average elevation in which the community was located. Communities at higher elevation (above 1000 meters above sea level) had a lower vulnerability index scores than those at lower elevations, as households in higher elevations will be less affected by increased temperatures. In this first stage, a random sample of communities was selected based on their vulnerability index scores. In the second stage, households in each of the selected communities were drawn from a census listing of coffee producers in the region. The households surveyed in this study form part of an ongoing project on climate change and food security conducted by the Center for International Tropical Agriculture.

Structured surveys were conducted with 236 coffee producing households, and information was gathered on main household characteristics, field-level and production statistics, cooperative information, and perceptions of climate change and its impacts. Of these 236 households, 14 were dropped from the analysis because the household head was not found, and the respondent (often a son or spouse) did not provide complete or reliable information. In addition, 10 households were dropped from the analysis due to missing data. After accounting for missing and incomplete data, I212 cases served as the basis for study.

Table 12. Sample Characteristics

Variable	Mean (% Where Noted)	Cooperative Member	
		No (n=129)	Yes (n=107)
Male (%)	65.4	60.7	39.3***
Age	46.4	44.5	48.8***
Household Size	5.4	5.2	5.4
Years of Education	3.8	3.7	3.9
Years in Coffee	16.5	14.5	16.5***
Total Coffee Income (USD) per ha	821.8	719.5	944.1**
Total Income	5,648.3	4,484.7	7,051.1**
Area Under Coffee Production (ha)	4.8	2.9	4.1***
Total Coffee Production (q[1]) per ha	9.7	6.4	7.2*

*[1]1 Quintal=46kg; Note: *, **, ***, indicates significance at 10%, 5%, and 1% level of significance*

Characteristics of the sample are presented in Table 11. The average age of the respondents is 46 years old with an average of 3.8 years of formal education completed. The mean area under production is 3.4 manzanas (2.4 hectares) and the mean annual coffee production is 6.8 quintales of wet parchment (312.8kg). Forty-six percent of the sample belongs to a coffee cooperative and 65% are male-headed households. I see that there are differences between the composition of the sample with respect to cooperative membership, amongst these differences gender composition emerges as significant, with a higher proportion of female members. In addition, older heads of household and those with more years of coffee experience are more likely to belong to cooperatives. Cooperative members also have significantly higher incomes and more land under coffee production than do non-members.

Table 13. List of Coffee Farming Practices

Practice	Definition	Benefits
Pest Management	Household controls pests in coffee fields.	Proper dosage of pesticides can help prevent pest outbreaks, such as leaf rust and coffee borer beetle.
Mulching	Household uses mulch in coffee fields.	Mulch helps with water retention and with weed control.
Erosion preventing walls	Household has built erosion preventing walls such hedgerows or other types of low walls	Erosion-preventing walls built in steep hills help with erosion and mudslides.
Water retention	Household has reforested around water sources.	Reforestation around water sources help with water evaporation and loss.
Water Harvesting	Household has built ponds to collect rainfall.	Water harvesting will become essential during droughts
Soil Analysis	Household has conducted soil analysis from their coffee fields	Soil analyses help determine how to properly fertilize soils
Green Manure	Household has planted nitrogen-fixing plants in their coffee fields.	Green manure is an organic practice that helps soil fertility
Shade Management	Household has planted shade trees in their coffee fields.	Shade helps with water retention, with erosion prevention, with temperature control, and provides alternative income opportunities
Pruning	Household has pruned their coffee trees.	Pruning coffee trees helps improve yields and control pests
Stumping	Household has stumped their coffee trees	Coffee trees need to be stumped about every 15 years, when productivity drops.

The main purpose of this study is to assess whether cooperative membership increases the likelihood of adoption of sustainable coffee production practices. Specific practices of interests were guided by the literature and interviews with key informants in the coffee sector of Nicaragua, which included agronomists, extension officers, and researchers. Ten practices emerge from these conversations and literature review: proper pest management, mulching, erosion preventing walls, water retention techniques, water harvesting, use of soil analysis, green manure application, shade management, pruning, and stumping; a definition of each of these practices, together with their role in helping build adaptive capacity are presented in Table 12.

Before turning to an econometric analysis of the impact of cooperative membership on adoption of practices, it is useful to compare how the rate of adoption of these practices differs amongst cooperative members and non-members.

Table 14. Comparison of Adopted Practices by Cooperative Membership

Practice	Cooperative Member			Chi-Square Test Statistic
	No (%)	Yes (%)	n (N=236)	
Pruning	86.05	91.59	209	1.77
Stumping	72.09	84.11	183	4.85**
Water Harvesting	31.78	38.32	82	1.10
Water Retention	80.62	87.85	198	2.26
Soil Analysis	13.95	32.71	53	11.81***
Pest Management	53.49	73.83	148	10.35***
Mulching	58.14	63.55	143	0.71
Green Manure	24.81	40.19	75	6.38**
Shade Management	87.6	91.59	211	0.98
Retention Walls	51.94	71.03	143	8.92***

*Note: *, **, ***, indicates significance at 10%, 5%, and 1% level of significance*

Table 13 reveals that the great majority of the sample has adopted certain practices, notably: shade incorporation, pruning, stumping and reforesting around water sources (water retention). Yet only a small proportion of the sample has adopted other practices such as soil analysis or planting nitrogen fixating plants (green manure). Perhaps most important for the current analysis is the finding that the rate of adoption of cooperative members is consistently higher among members than it is for non-members, although the differences are not always significant. Significantly higher rates of adoption by cooperative members are found in stumping, soil analysis, pest management, green manure application, and the installation of retention walls.

Turning to the potential economic impact of cooperatives, assessing this relationship is a more difficult task due to potential endogeneity problems associated with program placement and selection bias. Where farmers self-select into producers' cooperatives, their unobserved household characteristics may systematically differ from non-members. Many studies have chosen to treat cooperative membership as exogenous, and a few have used propensity score matching (Verhofstadt and Maertens, 2014a and 2014b; Abebaw and Haile, 2013), and treatment effect models (Weber, 2011), to control for this endogeneity. The approach used in this study, described below, is relatively new for this type of analysis and it offers a simple yet effective way to control for the potential endogeneity of cooperative membership (Wooldridge, 2015).

I employ the control function (CF) approach to control for systematic differences between cooperative members and non-members. This approach is useful when membership participation is non-linear, as CF estimators are more precise and robust than two-stage least squares (2SLS) (Rijkers *et al*., 2010) estimators. A drawback from the CF method, however, is that it forces us to make implicit distributional assumptions that are difficult to test (Rijkers *et al*., 2010).

I use the control function method to alleviate the self-selection bias of cooperative membership. This approach includes extra variables in the empirical specification to condition out the variation in the unobserved factor that is not independent of the endogenous variable (Petrin and Train, 2010). I follow Wooldridge's (2015) approach for handling discreet endogenous explanatory variables using the CF method.

A two-stage CF approach requires use of instrumental variables (IV) to test for endogeneity. The instrumental variable is a binary variable that indicates whether the producer was a cooperative member in 2013 (two years prior to data collection). The IV was tested and was found to be valid; in other words, it was correlated with the endogenous variable (current cooperative membership status) but was uncorrelated with ε, the error term in the explanatory model. The first stage involves regressing the instrumental variable on the suspected endogenous variable in a probit model (eq. 1). In the second stage, the generalized residuals from the model in the first stage are introduced as an explanatory variable into the structural model (eq. 3).

Stage 1: $$\pi_i^* = \alpha z_i + \nu, i = 1, \dots, n \quad (1)$$

Stage 2: $$Y_i = \beta X_i + \beta \pi_i + \hat{\nu}_i + \varepsilon, i = 1, \dots, n \quad (2)$$

In the first stage π_i^* is a binary variable indicating whether individual *i* belongs to a cooperative or not by the time of the study, z_i is the instrumental variable indicating whether individual *i* was a cooperative member in 2013, and ν is the error term which will be used in the second stage of the analysis.

In the second stage Y_i represents the number of practices adopted by the household (presented in Table 2) for farmer *i,* ranging from 0 practices to 10, X_i is a vector of household and farm characteristics, π_i^* is a dummy variable indicating whether the farmer belongs to a cooperative, β and α are a vector of parameters to be estimated by the model, $\hat{\nu}_i$ is the generalized error term estimated in the first stage, and ε is the error random term.

The degree to which cooperative membership affects the adoption of sustainable coffee production practices is studied in the second stage of the analysis, using ordered probit model (OPM)[6]. Ordered probit models allow us to estimate discreet dependent variables

[6] An OPM is employed in this study, in lieu of multinomial or poisson regressions, because it allows us to make distinctions between, for example, farmers who adopt only one practice versus those who adopt multiple practices in combination, whereas the alternative models treat the number of practices adopted as a count variable, assuming that the events have the same probability of occurrence (Wollni *et al*., 2010). The probability of adopting the first practice, however, could differ from the probability of adopting a second or third practice.

with multiple levels in which order matters and it is assumed to be incremental with unknown magnitude.

The econometric specification for this model, estimated in the second stage of the control function approach is the following:

$$y_i = \beta_1 CoopMember + \beta_2 \log(Income) + \beta_3 Area + \beta_4 HHsize + \beta_5 HHSex + \beta_6 HHEducation + \beta_7 HHAge + \beta_8 Radio + \hat{v}_i + e_i \quad (3)$$

Where y_{ij} represents the number of production practices adopted by producer *i*, and is modeled with household characteristics such size, age, education level, and sex of household head; farm characteristics such as area under coffee production; and other forms of capital, such as income and ownership of a radio. Radio ownership is included in the model because many rural households rely on them to obtain news and weather forecasts. The significance of cooperative membership is explored by introducing *CoopMember* in the model, the binary indicator that established whether the producer belongs to a cooperative. The endogeneity of cooperative membership is controlled through $\hat{v}_i$, the generalized residuals estimated in the first stage of the CF approach.

Results and Discussion

Table 14 shows the results from the ordered probit model, where the dependent variable represents the degree of adoption of the 10 practices described above.

Table 15. Ordered Probit Model Results

Practice Intensity	Coeff.	St. Error	
Ln(Income)	0.042	0.089	
Area	0.036	0.007	
HH Size	-0.092	0.035	***
Cooperative	0.991	0.377	***
Sex	-0.227	0.159	
Education	0.076	0.022	***
Age	0.002	0.005	
Radio	0.264	0.148	*
v_i	-0.318	0.241	
N	212		
Log likelihood	-411.53		
LR chi2(10)	54.05		
Prob > chi2	<0.000		

*Note: *, **, ***, indicates significance at 10%, 5%, and 1% level of significance*

The estimated coefficients in Table 14 predict the changes in the probability of adoption. I find evidence suggesting that the probability of adopting a higher number of practices increases with each additional year of education, and for households that own a radio; and that the probability of adopting a higher number of practices decreases with an increase in the number of household members. The variable of interest is how cooperative membership affects the probability of adoption, and the results provide strong evidence suggesting that the probability of adoption is higher for cooperative members than for non-cooperative members.

These results support the hypothesis that farmers who belong to cooperatives will be better prepared to combat the impacts of climate change, due to their adoption of a higher number of practices that give them greater adaptive capacity. The above model, however, does not differentiate between the quality or importance of practices, rather, it looks at how intensively, overall, farmers pursue a broad regime of sustainable practices. A closer look at the data provides further insight on the role of cooperatives in their support and promotion of practices to coffee farmers.

Characterization of Production Practices. Production practices can be characterized differently, from practices that require high labor investments to practices that require high capital investments. Households that have access to capital may be more likely to adopt capital-intensive practices, while household with limited capital might have access to more labor and thus may be more likely to adopt practices that require a greater investment of household labor. Understanding how these differences play out will give us more insight to whether and why households adopt certain practices and not others.

To capture some of these underlying structural differences, a factor analysis was conducted using the 10 sustainable coffee production practices included in the study. From this analysis, three factors were extracted, grouping the practices based on common characteristics as presented in Table 15.

Table 16. Characterization of Production Practices

Factor 1: Input Application	Practices that improve productivity of coffee through input application and soil fertility.	1. Soil Analyses from samples 2. Pesticides procurement and application 3. Mulch procurement and application 4. Green Manure procurement and application
Factor 2: Field Management Practices	Practices focused on better field management and plant health.	1. Pruning 2. Stumping 3. Shade Incorporation and Management (keeping it at 40%)
Factor 3: Water Conservation Practices	Practices focused on improved water conservation and management	1. Reforestation around water sources 2. Water Harvesting (building ponds for irrigation) 3. Building retention walls or hedgerows

The first factor consists of practices relevant to improved soil and plant fertility, through the application of inputs and the analysis of soils. The second factor consists of practices relevant to field management through the care of coffee trees and the use of shade in the field. The final group consists of practices related to the conservation and management of water resources. The use of retention walls to protect soils from erosion was initially grouped with practices in Factor 1, but given its thematic relevance, I moved it to the third group after ensuring its positive and high correlation with the water conservation practices in the factor analysis.

Using this categorization, three separate ordered probit models were estimated to determine whether there are differences in the determinants of adoption for the different types of practices. Most notably, I proceed to test whether cooperative membership is a significant determinant for any or all types of practices.

The first model looks at the determinants of adoption of input-oriented practices, where the dependent variable ranges from 0 to 4 in a scale of intensity of adoption, based on the number of practices adopted in this category. These practices are often subsidized by cooperatives or by public and private agencies through the provision of credit, subsidized extension services and/or inputs. I hypothesize that households with higher income and higher education levels will be more likely to adopt these types of practices. Households with higher income will have the capital to do so, and households with higher education are more likely to be literate and able to access information and other resources, giving them a better understanding of the effects of adoption on productivity.

The second model measures the determinants of adoption of practices involving field and plant management, the dependent variable measures the intensity of adoption of these practices and it ranges from 0 to 3. These are practices that often require high labor dedication. I hypothesize that bigger households and households with higher income will be more likely to adopt these practices as they have the means to allocate household labor or to hire labor.

Finally, in the third model I measure the determinants of adoption of water conservation practices, which range in intensity from 0 to 3. These practices are especially relevant, given their potential for climate change mitigation strategies. I hypothesized that households with higher income and higher education will be more likely to have adopted these practices. The overarching hypothesis is that cooperative membership is positive and significant in all three models, particularly in the third one, because it consists of practices that are not yet commonly used in the coffee sector, and are in the early stages of adoption. Results from these analyses are presented in Table 16.

Table 17. Ordered Probit Model Results for Disaggregated Practices

Variable	*(1) Input Practices*	*(2) Field Practices*	*(3) Water Practices*
Ln(income)	0.044	-0.090	0.079
Area	0.019	0.074**	0.026
HH Size	-0.081**	-0.109***	0.004
Cooperative	0.469	0.644	1.183***
Sex	-0.121	-0.241	-0.227
Education	0.048**	0.086***	0.062***
Age	-0.006	0.005	0.004
Radio	0.226	0.367*	0.096
v_i	0.029	-0.264	-0.615**
N	212	212	212
Log likelihood	-305.1	-168.4	-247.5
LR chi2(9)	31.90	32.97	31.55
Prob > chi2	0.0002	0.0001	<0.0002
Pseudo R2	0.049	0.089	0.059

*Note: *,**,***, indicates significance at 10%, 5%, and 1% level of significance*

Results from these models provide further insight into the role of cooperative membership in the adoption of production practices. I find that cooperative membership has a significant effect on adoption only in the third model. But before discussing each model in greater depth, we compute the marginal effects of the significant variables to make interpretation of the coefficients easier, these marginal effects are presented in Table 17.

Table 18. Marginal Effects of Significant Variables on Adoption Intensity

Intensity of Practice	*(1) Input Practices*		*(2) Field Practices*				*(3) Water Practices*	
	HH Size	Educ	Area	HH Size	Educ	Radio	Coop	Educ
0	*0.014	-0.008	-0.002	*0.004	-0.003	-0.012	-0.148	-0.001
1	*0.017	-0.011	-0.009	*0.013	-0.01	-0.043	-0.249	-0.015
2	-0.005	*0.003	-0.014	*0.020	-0.016	-0.068	*0.063	*0.005
3	-0.015	*0.008	*0.025	-0.037	*0.029	*0.123	*0.334	*0.017
4	-0.012	*0.066						

Model 1 looks at the determinants of adoption of practices that help improve health and soil nutrition of coffee fields through the application of inputs. I find that producers with higher education levels are more likely to adopt and that household size is a significant and negative determinant of adoption. This runs counter to our hypothesis that larger households are able to allocate more household labor to their farms, and hence are more likely to adopt these types of practices. Further studies should look at household dependency ratios, or the number of active adults, as these results could represent households with a low proportion of active members who are able to support farm efforts. I find that each additional year of education improves the odds of adoption of all four practices in this first model by 6.6 percentage points, and that for each additional household member the odds of adoption of all four practices decrease by 1.2 percentage points.

Model 2 looks at the determinants of adoption of field management practices, these include the use and management of shade, and pruning and stumping of coffee trees. In this model I see three variables that emerge as positive and significant: area under coffee production, education and ownership of a radio. Household size surprisingly, as in the first model, is a negative and significant determinant of adoption. The practices included in this model are practices that are generally considered to require higher labor demands, and I expected that larger households would have more available labor to allocate to these types of practices, yet the results suggest something different. Households that do not own a radio are 1.2% more likely to have not adopted any of the practices in this category. Each additional year of education increases the odds of adopting all three practices by 2.9%, and each additional manzana of land increases the same odds by 2.5 percentage points.

In the third and final model I measure the determinants of adoption of practices that improve water retention and conservation. This set of practices is particularly relevant to agricultural households facing increasing rates of droughts and extreme rainfall. In 2010, for example, Nicaragua experienced intense and sustained rainfall in which entire crops were wiped out, this was followed by a drought in 2012 which saw historically low rainfall, also resulting in massive crop losses (Gourdji *et al*., 2014). The incidence of extreme weather events is projected to increase with climate change, making it critical to plan for agricultural adaptation. Cooperative membership and education are the two variables that emerge as significant and positive in this model. I find that non-cooperative members are 14.8% more likely than members to have no practices adopted in this category, and 24.9% more likely to have only adopted one practice, in comparison with cooperative members.

By contrast, I find that members are 6.3% more likely to have adopted two out of the three practices and 33.4% more likely to have adopted all three practices in this category than are non-members. These results are encouraging, as water conservation and harvesting can supply supplemental irrigation during droughts, and perhaps even more important, sufficient soil moisture helps crops cope with higher temperatures through transpirational cooling (Lobell *et al.,* 2011).

Cooperative membership does not emerge as significant in models 1 and 2 and this is a surprising finding given the overwhelming literature that finds that cooperative membership to be a significant determinant of adoption of new technologies and agricultural practices. Three possible explanations are considered to help account for these differences. First, some studies that measure cooperative membership as a determinant of adoption, do not account for the potential endogeneity of membership, possibly misattributing significance to membership when none actually exists. Second, many studies that look at the determinants of adoption of technologies and practices often stop after modeling practices in an aggregate manner. This study is different in that a factor analysis is used to identify and extract the underlying structural characteristics that unify groups of practices and give us insights into the determinants and patters of adoption of practices. And finally, although cooperative membership is not statistically significant in these two models, it is important to note that the direction of the relationships are positive and thus consistent with the literature. We expect that a study replication with a larger sample could find that cooperative membership does in fact emerge as a significant determinant of adoption across all groups of practices. It is important to mention that this lack of significance could be attributed to the already high adoption rate of these practices. As shown at the outset, a large proportion of farmers in Matagalpa have already adopted the majority of these practices, making it more difficult to discern the effects of cooperative membership.

The generalized residuals variable used to control for the endogeneity of cooperative membership is significant only in the third model. This implies that there are unidentified characteristics that can explain the adoption of practices that promote water conservation, variables that are not modeled in this analysis.

Conclusion

This study analyzes the determinants of adoption of sustainable production practices by coffee farmers in Nicaragua and it looks at the degree to which coffee cooperatives play a significant role in increasing the capacity of farmers to adopt these practices. Past research has shown that farmers who belong to farmers' associations or cooperatives are financially better off than those who do not (Jena *et al*., 2012; Wollni and Zeller, 2007), and that cooperative membership is a significant determinant of adoption of technologies and production practices (Verhofstadt and Maertens, 2014a; Wollni *et al*., 2010). I find that cooperative membership is a positive and significant determinant of adoption of sustainable production practices overall, and more significantly, that farmers who belong to cooperatives have higher odds of adopting practices that help with water conservation.

Amongst all the practices studied in this research, the water conservation practices are perhaps the most relevant to climate change adaptation. Reforestation around water sources is one of these practices, this practice helps to protect water sources, such as streams, ponds, and wells; it also helps to prevent erosion and water runoff, and it helps to protect the biodiversity of the area. A second practice is the use of retention walls, these walls play an important role in preventing soil erosion. With seasons marked with longer periods of drought followed by short, erratic, and severe rainy seasons, fields located on steep slopes are particularly susceptible to potential mudslides and erosion and these walls can help diminish some of these risks. Finally, water harvesting is a technology that helps farmers to collect rainwater and ground water for irrigation of fields, a practice that will become increasingly important with drought becoming a more common occurrence in the region.

Future research should develop an institutional framework to analyze the emergence of cooperatives in Nicaragua and study how they have shaped farmers' perceptions of collective action and their likelihood of joining one. Further research, which relies on both qualitative and quantitative measures, could help us evolve the understanding of how cooperatives operate and how they work with their members.

The policy implications of this study are relevant and applicable to many coffee-producing countries around the world. In order to meet the growing global demand for coffee and to prevent the negative economic and environmental impacts of climate change on coffee producers, cooperatives and other agricultural organizations can be instrumental in developing strategies that reach producers and helping them to build adaptive capacity in response to these changes. Climate change will affect the suitability of coffee growing regions around the world; indeed the pressures from climate change may force some producers to move out of coffee production entirely, but those who remain will need climate adaptation support and cooperatives are strategically well placed to help provide such support.

REFERENCES

REFERENCES

Abebaw, Degnet, and Mekbib G. Haile. "The impact of cooperatives on agricultural technology adoption: Empirical evidence from Ethiopia." Food policy 38 (2013): 82-91.

Baca, María, Peter Läderach, Jeremy Haggar, Götz Schroth, and Oriana Ovalle. "An integrated framework for assessing vulnerability to climate change and developing adaptation strategies for coffee growing families in Mesoamerica." *PloS one* 9, no. 2 (2014): e88463.

Barrett, Christopher B. "Smallholder market participation: concepts and evidence from eastern and southern Africa." *Food Policy* 33, no. 4 (2008): 299-317.

Donovan, Jason, and Nigel Poole. "Changing asset endowments and smallholder participation in higher value markets: Evidence from certified coffee producers in Nicaragua." Food Policy 44 (2014): 1-13.

Fischer, Elisabeth, and Matin Qaim. "Linking smallholders to markets: determinants and impacts of farmer collective action in Kenya." World Development 40.6 (2012): 1255-1268.

Greene, William H., and David A. Hensher. Modeling ordered choices: A primer. Cambridge University Press, 2010.

Gourdji, Sharon*, et al*. "Sustainable Development Opportunities at the Climate, Land, Energy, and Water Nexus in Nicaragua." Center for Latin American Studies, Working Paper 33 (2014).

Jena, Pradyot Ranjan, et al. "The impact of coffee certification on small-scale producers' livelihoods: a case study from the Jimma Zone, Ethiopia."Agricultural economics 43.4 (2012): 429-440.

Laderäch, Peter, Carlos Zelaya, Oriana Ovalle, Samuel Garcia, Anton Eitzinger, and Maria Baca. "Escenarios del Impacto del Clima Futuro en Areas de Cultivo de Cafe en Nicaragua." CIAT Blog. 13 Mar. 2013. Web. http://dapa.ciat.cgiar.org/wp-content/uploads/2012/03/Informe-Nicaragua-final.pdf

Laderäch, Peter, et al. "Predicted impact of climate change on coffee supply chains." The Economic, Social and Political Elements of Climate Change. Springer Berlin Heidelberg, 2011. 703-723.

Lobell, David B., *et al*. "Nonlinear heat effects on African maize as evidenced by historical yield trials." Nature Climate Change 1.1 (2011): 42-45.

Mendez, V. Ernesto, et al. "Agrobiodiversity and Shade Coffee Smallholder Livelihoods: A Review and Synthesis of Ten Years of Research in Central America*." The Professional Geographer 62.3 (2010): 357-376.

Louhaichi, Mounir, et al. "Financial incentives: Possible options for sustainable rangeland management?." Journal of Environmental Management 180 (2016): 493-503.

Ovalle-Rivera, Oriana, Peter Läderach, Christian Bunn, Michael Obersteiner, and Götz Schroth. "Projected Shifts in Coffea arabica Suitability among Major Global Producing Regions Due to Climate Change." (2015): e0124155.

Perfecto, Ivette, et al. "Shade Coffee: A Disappearing Refuge for Biodiversity." BioScience 46.8 (1996).

Perfecto, Ivette, et al. "Shaded coffee and the stability of rainforest margins in northern Latin America." Stability of Tropical Rainforest Margins. Springer Berlin Heidelberg, 2007. 225-261.

Petrin, Amil, and Kenneth Train. "A control function approach to endogeneity in consumer choice models." Journal of Marketing Research 47.1 (2010): 3-13.

Ponte, Stefano. "Thelatte revolution'? Regulation, markets and consumption in the global coffee chain." *World development* 30, no. 7 (2002): 1099-1122.

Rijkers, Bob, Caterina Ruggeri Laderchi, and Francis Teal. "Who benefits from promoting small and medium scale enterprises? Some empirical evidence from Ethiopia." Some Empirical Evidence from Ethiopia (May 1, 2008). World Bank Policy Research Working Paper Series, Vol (2008).

Valkila, Joni. "Fair Trade organic coffee production in Nicaragua—Sustainable development or a poverty trap?." Ecological Economics 68.12 (2009): 3018-3025.

van Rikxoort, Henk, Götz Schroth, Peter Läderach, and Beatriz Rodríguez-Sánchez. "Carbon footprints and carbon stocks reveal climate-friendly coffee production." Agronomy for Sustainable Development (2014): 1-11.

Verhofstadt, Ellen, and Miet Maertens. "Smallholder cooperatives and agricultural performance in Rwanda: do organizational differences matter?."Agricultural Economics 45.S1 (2014a): 39-52.

Verhofstadt, Ellen, and Miet Maertens. "Can Agricultural Cooperatives Reduce Poverty? Heterogeneous Impact of Cooperative Membership on Farmers' Welfare in Rwanda." Applied Economic Perspectives and Policy(2014b): ppu021.

Vermeulen, Sonja J., et al. "Addressing uncertainty in adaptation planning for agriculture." Proceedings of the National Academy of Sciences 110.21 (2013): 8357-8362.

Virapongse, Arika, et al. "A social-ecological systems approach for environmental management." Journal of environmental management 178 (2016): 83-91.

Weber, Jeremy G. "How much more do growers receive for Fair Trade-organic coffee?." Food Policy 36.5 (2011): 678-685.

Wollni, Meike, David R. Lee, and Janice E. Thies. "Conservation agriculture, organic marketing, and collective action in the Honduran hillsides." Agricultural Economics 41.3-4 (2010): 373-384.

Wollni, Meike, and Manfred Zeller. "Do farmers benefit from participating in specialty markets and cooperatives? The case of coffee marketing in Costa Rica1." Agricultural Economics 37.2-3 (2007): 243-248.

Wooldridge, Jeffrey M. "Control function methods in applied econometrics." Journal of Human Resources 50.2 (2015): 420-445.

Chapter 5: Conclusions

"Saving our planet, lifting people out of poverty, advancing economic growth... these are one and the same fight. We must connect the dots between climate change, water scarcity, energy shortages, global health, food security and women's empowerment. Solutions to one problem must be solutions for all."

Ban Ki-Moon

From the chapters in this dissertation, a picture begins to emerge, describing a sector in great peril, yet with high potential. Coffee in Nicaragua is the main source of income for thousands of smallholder producers, and is the country's most important agricultural export. Given the vulnerability of coffee to the impacts of climate change there is a consensus amongst scientists, development practitioners and policy makers that adaptation strategies are imperative and in some cases urgently needed to ensure a sustainable future for the coffee value chain, and especially for the producers who depend on coffee production as their main source of income.

The dissertation starts with a broad description of the characteristics of coffee farmers in Matagalpa, exploring their capacities and incentives for climate change adaptation, including an exploration of their attitudes towards risk. It continues with an analysis of the conditions under which farmers choose to incorporate shade into their coffee fields; a practice that helps to promote biodiversity conservation and known to mitigate some of the impacts of climate change. Finally, I conclude by analyzing how and the degree to which cooperatives support farmers in the adoption of improved production practices that enable them build adaptive capacity to climate change.

How will these coffee producers cope with higher temperatures, droughts, and erratic and extreme rainfall? There is no doubt that the institutional capacity of organizations within the sector will play an important role. The research shows that farmer cooperatives can and do provide many services to farmers, from input provision to trainings and extension services. And I have learned that farmers who belong to cooperatives tend to adopt practices that help them build adaptive capacity to climate change, in particular, through the adoption of water conservation practices. Yet I have also learned that about 74% of farmers who belong to cooperatives are not satisfied with the services that their cooperatives provide and that when the 2012 leaf rust outbreak began damaging coffee trees and reducing yields, the response from cooperatives and other organizations within the sector, was seen as woefully insufficient. Farmers reported that pesticides were provided that did not work to eliminate the leaf rust, and that without an effective solution, the leaf rust spread and resulted in a catastrophic yield reduction and plant loss. Nearly 75% of farmers in the sample reported losses due to plant diseases, many of them uprooting their coffee trees and establishing varieties reported to be more resistant to leaf rust, yet of lower coffee quality.

It is for this reason, then, that building better institutional capacity within the organizations that serve farmers must be prioritized. I know, from this work and from a review of the literature, that organizations can help farmers in measurable ways, such as through the provision of inputs and trainings, as well as more indirectly through the creation of social capital and safety nets. I have also observed that in Nicaragua issues of mismanagement and corruption have tarnished the reputation of many of these organizations; compounded upon this are problems arising from the leaf rust epidemic. An important task ahead, then, lies in strengthening the capacity of cooperatives and other organizations to enable farmers to cope with natural shocks as they become more challenging and more frequent. An approach that incorporates scientific knowledge on effective strategies that coffee farmers can adopt, together with institutional capacity building for the organizations already in place to support improved management of their resources must be implemented together.

This work also highlights the importance of developing interventions that account for the preferences and needs of marginalized populations. In Nicaragua, and around the globe, women are disadvantaged in their access to goods and services. The women in the sample not only have less land to grow coffee, but the land that they own is less productive and yields less income. Additionally, these women are significantly more food insecure than their male counterparts. Food insecure households, defined as households that lack sufficient and nutritious food, are also less prone to making riskier choices, I find. While such choices may be beneficial for households that cannot afford to compound their already existing vulnerabilities with added risk, for other households it may mean missing out on potential opportunities brought by the adoption of improved technologies and production practices, opportunities that hold potential for building adaptive capacity in the face of a changing climate.

I believe that a multidimensional and customizable approach is needed in support of farmer organizations in a position to promote farm-level adaptive capacity to climate change. What works for some may be ineffective for others, and special attention must be given to issues of equity and access.

Despite the vulnerability of coffee growing regions to declining crop suitability due to climate change, there is also great potential in the response of the sector to this threat. During the years in which the demand for coffee was growing, many policies promoted the intensification of coffee production, endangering the biodiversity richness that traditional coffee farms often enjoyed. The results from this research suggest that if the price of coffee goes up, increasing coffee farmer incomes, farmers will be more willing to introduce shade trees into their farms. This is an important innovation that helps at all levels of the value chain and beyond. It improves the suitability of the farms for coffee production, which in turn protects the livelihoods of coffee farmers (through income generation and alternative food sources). Additionally, planting shade trees helps to conserve biodiversity, protect the soils, and serves as a refuge for migratory species. With an eye to the longer-term viability of the country's coffee sector, there is good reason to believe that even small coffee price incentives for shade grown coffee will result in positive human and natural synergies and a more sustainable future for coffee in Nicaragua's Matagalpa region.