Economic Feasibility of a Biological Control Cottage Industry in Niger

Michael J. Guerci

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Agricultural and Applied Economics

George Norton, Chair
Jeffrey Alwang
Daniel Taylor

August 3rd, 2016
Blacksburg, VA

Keywords: Niger, economic feasibility assessment, biological control, millet

Economic Feasibility of a Biological Control Cottage Industry in Niger

Michael J. Guerci

ABSTRACT

This study evaluates the economic feasibility of a biological control industry in Niger. Farmers in the Sahel region of Niger are vulnerable to high millet yield losses due to the millet head miner, and their pest control options are extremely limited. Researchers have begun to support small businesses which sell a beneficial insect (*Habrobracon Hebetor*) that is very effective in limiting millet yield losses due to the millet head miner. This study discusses a wide range of questions related to the economic prospects of these businesses using two main analytical methods, an economic feasibility assessment and an econometric analysis. The economic feasibility assessment provides budget analysis for the potential businesses and discusses business options for scaling, price setting, and organizing. A central question in this analysis is whether farmers can cooperatively purchase beneficial insects as a means of preventing free-riding. With free-riding as a prominent concern for businesses, this study also provides an econometric analysis of the factors that affect farmer’s willingness-to-pay for beneficial insects.

Acknowledgments

Thank you to USAID and the Kansas State University Sorghum and Millet Innovation Lab for funding this project. Thank you to my committee members George Norton, Dan Taylor, and Jeff Alwang for all your guidance over the course of my time at Virginia Tech. It was a pleasure working with each of you, and to Dr. Norton, I am very grateful that you chose me to work on this project. Travelling to Niger with you was a very gratifying experience that I will never forget. I must also thank my friends from Niger who made my thesis possible. Thank you to Ibrahim Baoua, Malick Ba, Laouali Amadou, Oumou Moumouni, and Laouali Karimoune. A special thanks to Laouali Amadou who was a vital source of information for me during his time as a visiting scholar at Virginia Tech and a great friend. Another special thanks to Oumou Moumoni who showed great kindness to me during my time in Niger and during her time in Blacksburg. Thanks to my great friends in Blacksburg. You are all wonderful, and I couldn’t have done this without you. A final thanks to my parents and family, for your love and support over the years.

Table of Contents

Chapter I. – Introduction

I.1. Problem Statement

In order to improve livelihoods in Niger, agricultural development is a sensible target because Niger's population overwhelmingly consists of poor, subsistence farmers. Agriculture accounts for 80% of the Nigerien labor force and 40% of the country's GDP (World Bank, 2013). Farmers in Niger especially rely on pearl millet, a cereal crop that is critical to the livelihoods of people in the semi-arid Sahel region of West Africa. A significant source of proteins, vitamins, and dietary fiber (Amadou et *al*., 2013), millet is the predominant staple food in the Sahel, as it is suitable for land with poor soil and low rainfall where most other grains cannot grow. Niger, with almost all of its arable land in the Sahel, produces the third most millet of any country in the world, most of which is consumed domestically (FAO, 2014). Niger's reliance on domestic millet is reason to prioritize research on millet production stability, especially as Niger is constantly at-risk for food crises due to drought and pests.

This study focuses on the most problematic millet pest in Niger. The millet head miner (*Heliocheilus albipunctella*) has been shown to cause annual millet yield losses up to 85% if untreated (Gahukar et *al*., 1986; Nwanze and Sivakumar, 1990; Krall et *al*., 1995; Youm and Owusu, 1998). Common pest control techniques, including spraying pesticides, breeding for host plant resistance, and using cultural controls, are ineffective or impractical (Gahukar 1989, 1990, 1992; Nwanze and Sivakumar 1990). The release of a beneficial insect has emerged as the only viable and effective control strategy for the millet head miner problem. The *Habrobracon hebetor* (*H. hebetor*) is a small wasp parasitoid that has been shown to parasitize up to 97% of millet head miner larvae resulting in yield increases of up to 41% on infested plants (Ba et *al*., 2013; Baoua et *al*., 2014). Further research is being conducted to optimize the effectiveness of *H. hebetor*'s release, and other parasitoids are being tested as alternatives.

H. hebetor and the millet head miner are both native species to Niger, and until recent decades, *H. hebetor* exhibited a natural parasitism of millet head miner of 64-95% (Guevremont, 1983; Bhatnagar, 1984). Recently however, Niger is no longer a suitable place for the beneficial parasitoids to naturally build and maintain a population large enough to mitigate millet losses due to the millet head miner. Consequently, a pest control strategy using *H. hebetor* necessitates an annual augmentation of the species into the environment. Since 2006, mass releases have been conducted in Niger, Mali, and Burkina Faso (Baoua et *al*., 2014) as part of a project funded by the McKnight Foundation. The Institut National de la Recherche Agronomqiue du Niger (INRAN) along with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) are interested in finding an efficient system for widespread annual dissemination of the beneficial insects to farmers throughout the millet-growing regions of Niger. These organizations have been instrumental in developing effective rearing and release techniques for *H. hebetor*, but they do not have the capacity for annually breeding and distributing beneficial insects on a large scale. Consequently, they hope to catalyze a small cottage industry composed of small private businesses that are responsible for rearing insects, selling insect bags to farmers, and advising farmers on the optimal techniques for releasing insects in fields. Commercialization of the *H. hebetor* will generate opportunities for wider geographic distribution of the technology, sustain the availability of the biological control over a longer duration, and create jobs.

The feasibility of an *H. hebetor* cottage industry appears promising when considering basic details of supply and demand. Minimal capital investment is needed to raise the insects, and the labor is not intensive. Maintaining the insects takes little time during the majority of the year and only requires full-time work for a couple of summer months when it is time for mass multiplication and distribution of the insects. Furthermore, the technology is very effective, and many interviewed farmers have indicated that they are willing to purchase bags of the *H. hebetor* (Ba et al., 2013). Budget analysis will help prospective businesses understand the potential for profitability in selling *H. hebetor*.

Private commercialization may be the most economically solvent approach to meeting the needs of farmers, but it is important for public research institutions to play a role in setting the commercialization process in motion due to the nature of both the market and the technology. The market consists of poor subsistence farmers living in scattered, sometimes isolated rural areas. With a vested interest in the livelihoods of these farmers, research institutions would like to ensure that the technology is available to as many farmers as possible, which will necessitate the geographic coordination of businesses and an analysis of product affordability. Research can build knowledge on price-setting options and the potential geographic scope of the market.

Another consideration in the commercialization process is that the biological control technology potentially creates a public good problem. *H. hebetor* in open fields will spread up to 5 km from release point, and since all farmers within a certain radius of the release will benefit from the parasitoids' pest-killing services, *H. hebetor* can be thought of as a public good that produces positive externalities for neighboring farmers. Farmers will have the incentive to wait for their neighbors to buy the beneficial insects so that they can realize benefits for the least cost. Large-scale free-riding can cause a market to collapse if the producer of the public good is not receiving sufficient benefits relative to costs. To prevent free-riding, this study advocates that farmers cooperatively purchase the beneficial insects at the village level. A cooperative purchasing arrangement could potentially take advantage of pre-existing farmer federation networks in Niger that provide cooperative farmer groups with input supplies, financial services, and farm consultation. With free-riding as a prominent concern, businesses could benefit from an improved understanding of the farmers who are most likely to free-ride. Information on the factors that affect farmers' willingness-to-pay for beneficial insects may help inform business interventions which may in turn increase the likelihood that farmers contribute to cooperative purchases.

In sum, the *H. hebetor* appears to be a promising solution for limiting pest losses in Niger's staple crop, but a market for *H. hebetor* will face economic challenges that could be difficult to overcome without careful planning and coordination. A parasitoid cottage industry will benefit from analyses that help businesses build knowledge about their options for scaling, organizing, price setting, and marketing.

I.2. Study Objectives

The purpose of this study is to assess the benefits and costs of establishing a beneficial-parasitoid cottage industry and to build knowledge about farmers' free-riding potential. Researchers and business owners can use this information to plan and develop a small industry in a manner that accommodates their goals. Specific research objectives are as follows:

1. Document the equipment and operational timeline needed to rear and sell *H. hebetor*.
2. Evaluate the profitability potential of individual businesses.
3. Assess whether individual farmers are willing to pay a price for parasitoids in a cooperative purchasing scheme that provides adequate profits to sustain biocontrol businesses, while providing an acceptable net return for farmers.

4. Describe potential business risks and hypothesize ways in which businesses might adapt to these risks.
5. Compare worker wages to wages of comparable employment.
6. Examine the potential geographic scope of the entire market, which has important consequences for market planners and individual businesses.
7. Estimate the effects of farmer characteristics on willingness-to-pay for beneficial insects.

I.3. Approach

This paper is informed by two main analytical components: (1) a business feasibility assessment for *H. hebetor* businesses; and (2) an econometric analysis of the factors that affect farmer willingness-to-pay for *H. hebetor*. The feasibility assessment is organized into sections that focus on seven components: operations, profitability, affordability, risk, worker benefits, farmer benefits, and total market potential. The main analytical component of the feasibility assessment is a flexible enterprise budget framework that provides a menu of profit scenarios by adjusting business-level decision-making variables. Key variables include sale volume and price. The study also theorizes a cooperative purchasing scheme and evaluates its potential to help all farmers achieve mutually beneficial outcome.

For the willingness-to-pay assessment, a linear regression model is estimated. The key variables in the model indicate whether or not a farmer has previously used the beneficial insect and whether or not a farmer belongs to a farmer organization. These variables are important because they have the potential to inform interventions that could encourage greater stability among the demand base for the beneficial insect market. For example, if farmers who have received free distributions of beneficial insects exhibit higher levels of willingness-to-pay, it may be an effective policy to organize the distribution of more “free samples” of insects to villages in order to encourage greater public interest in the product. If members of farmer organizations exhibit a higher propensity to pay for insects, businesses may be encouraged to target farmer organizations as a marketing channel but also to strengthen marketing toward non-members who are less likely to participate in cooperative purchases.

I.4. Organization of Study

Chapter II presents a description of the study area and a literature review of issues surrounding the control of the millet head miner. Chapter III details concepts that are relevant to the central analyses of this study, including public goods, cooperative clubs, contingent valuation, willingness-to-pay theory, and factors that affect willingness-to-pay. Chapter IV documents the methodology behind the business feasibility assessment and the regression analysis. Chapters V and VI present the results of the business feasibility assessment and regression analysis, respectively. Chapter VII concludes with summarizing discussion.

Chapter II. – Background and Literature Review

Chapter II provides background information on a wide range of topics that are essential to understanding the context for a potential biological control industry in Niger. Background information is grouped into four broad categories: (1) study area, (2) biological control, (3) key institutions, and (4) the 2015 business pilot-test.

II.1. Study Area

In the latest Human Development Report published by the United Nations Development Programme, Niger received the lowest development index ranking (188th out of 188 countries).

Gross national income (GNI) per capita was US $908 with 72.2% of the working population earning below US $2 per day and 40.8% of the working population earning less than $1.25 per day (UNDP, 2015). Niger's birth rate is the highest in the world, and over 89% of the population is considered to be in multidimensional poverty (Central Intelligence Agency, 2016; UNDP, 2015). Mean years of schooling is 1.5 years, and the adult literacy rate is 15.5% (UNDP, 2015).

II.1.a. Geography and Climate

Niger is a landlocked country in West Africa with a territory of 1,270,000 square kilometers. The country is largely composed of desert or semi-desert climate. There are four general rainfall zones in Niger (Mohamed et *al*., 2002): (i) the Sahara zone with 0-200 mm of annual rainfall (67% of total area), (ii) the Sahel-Sahara zone with 200-350 mm (20%), (iii) the Sahel zone with 350-600 mm (10%), and the Sudanian zone with over 600 mm (3%). Climatic zones are shown in Figure 1. Figure 2 illustrates the seven administrative regions of Niger, of which all but Agadez have territory within the Sahel. Only one quarter of land is suitable for cultivation, and most of this suitable land has severely limited agricultural potential. Droughts, desertification, and soil erosion exacerbate agricultural vulnerability.

II.1.b. Agricultural Economy

The agriculture sector is the second largest contributor to Niger's GDP, behind services. Subsistence rain-red agriculture and stock rearing accounted for 40% of the country's GDP and employed more than 80% of working adults (World Bank, 2013). A typical farm in Niger averages 4.1 hectares and utilizes traditional farming techniques with limited use of mechanized equipment, improved seed varieties, or fertilizer. Food insecurity and a growing population contribute to increased pressure to cultivate lands with low and variable rainfall. Farms predominantly produce millet, sorghum, and cowpea as these crops are well-suited for hot climates with little rainfall. Less prominent crops include peanut, cassava, sweet potato, rice, maize, and wheat. Niger annually produces approximately 3.5 million tons of cereals which are complemented by thousands of tons of international food aid (World Bank, 2013).

Figure 1: Climatic Zones in Niger
(National Adaptation Programme of Action, 2006)

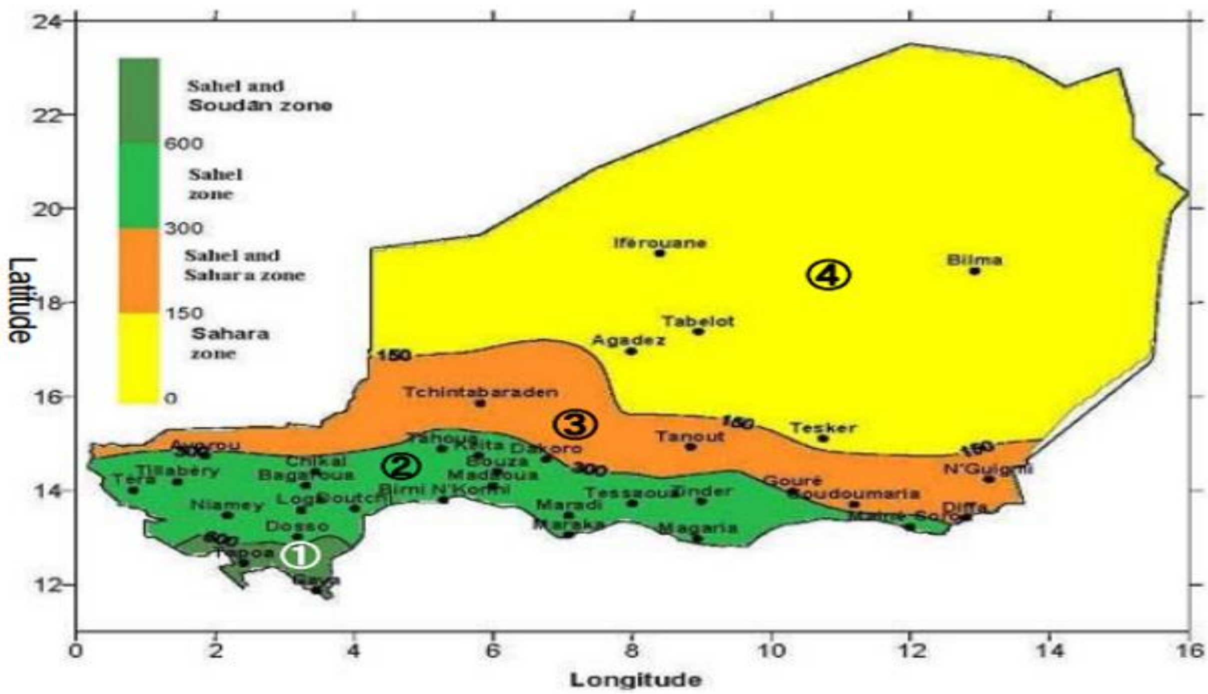


Figure 2: Regions of Niger

II.1.c. Food Insecurity

Over 50% of Niger's population is considered to be chronically food insecure, and about 22% of the population is considered at-risk of extreme caloric inadequacy (Aker et *al*., 2009). Nigeriens exhibit low per capita food consumption, high micronutrient deficiency, and limited dietary diversity. Over 50% of household expenditures for the lowest income quintile are spent on cereals, a significantly higher level than in developed countries (Aker et *al*., 2009).

There are many environmental, political, and economic factors that contribute to Niger's high level of food insecurity, namely droughts, pests, floods, price volatility, and political instability. Drought poses the highest risk to food security in terms of probability and severity (World Bank, 2013). A drought can occur because of low seasonal rainfall or abnormal rainfall such that crops are not watered at crucial times in their growing cycle. Niger experienced seven major droughts associated with crop failure between 1980 and 2010 (1984, 1987, 1993, 1997, 2000, 2004, and 2009). Consequences of droughts include food shortages, land and water conflicts, spikes in food prices, increased pest pressure, and increased livestock mortality. In the last fifteen years, Niger appealed for international food aid in 2001, 2005, 2010, 2012, and 2014 due to severe food shortages (World Bank, 2013).

There is a lack of reliable data on crop damage caused by pests, but pests are generally considered one of the greatest risks to food security in Niger. Locusts, which swarm and eat all vegetation in their path, are the most devastating pest for farmers, but the damage is erratic and often highly localized. Other common insect pests include the millet head miner, the millet stem borer, and the grasshopper. The millet head miner is consistently the most serious millet pest in the country, capable of causing millet yield losses of up to 85% (Gahukar et *al*., 1986; Nwanze and Sivakumar, 1990; Krall et *al*., 1995; Youm and Owusu, 1998). In a survey of 100 Nigerien farmers in 20 villages, fifty percent of farmers identified the millet head miner as the main insect pest of millet, and ninety-one percent of farmers perceived high damages from the millet head miner (Ba et *al*., 2013). The same farmers estimated 40% average yield losses from the millet head miner.

II.1.d. Importance of Millet to Study Area

Niger produces the third most millet of any country in the world, most of which is consumed domestically (FAO, 2014). Pearl millet is the most important staple crop in Niger, accounting for almost 70% of cereal production (Annuaire Statistique de Niger, 2012). The millet plant's stover is also used as animal forage and roof construction material. Millet accounts for the majority of cereal production in Niger because it can grow where most other grains cannot (JAICAF, 2009; FAO, 2014). It is commonly grown on marginal lands with high temperatures, low and variable rainfall, short rainy seasons, high evaporation rates, and soils with a low water-holding capacity (Mohamed et *al*., 2002).

II.2. Biological Control

Commercial production of beneficial insects is typically associated with "augmentative biological control," a technique that involves the periodic release of natural enemies. Augmentative biocontrol is often a commercial endeavor because of the need for regular releases of large quantities of insects (van Lenteren, 2011). Natural enemies are commonly mass-reared in biofactories that can produce large numbers in order to achieve immediate control of pests (van Lenteren, 2011). This is a markedly different approach from "classical (or inoculative) biological control" which involves a one-time introduction of a species to a new area in order to allow its population to build over time and suppress a problematic pest. Augmentative biological control can involve native or exotic species, but due to concerns about the consequences of releasing exotic species, native species are usually the first solution to be considered. *H. hebetor* is a native species to Niger, and it has been used as a pest management solution since 1962 when it was introduced in Taiwan to control the sugarcane pink borer (Cheng, 1991).

Biological control is considered one of the most cost-effective and environmentally-safe pest management options (Cock *et* al., 2010). Mass commercial production of biological control agents has occurred for over 120 years, and today there are approximately 230 species of natural enemies that are commercially available (van Lenteren, 2011). The most important commercial markets (in terms of sale value) are for greenhouse crops in Europe and the United States, although there is considerable potential for markets to emerge for field crops around the world (van Lenteren, 2011). In 2008, Africa accounted for only 2% of the commercial augmentative biological control market share, but it represents a growing market segment (Cock et *al*., 2010). In Niger, biological control agents are not a readily available pest management option for farmers, but biological control using indigenous parasitoids has been identified as a promising millet head miner control strategy since the 1980s (Gahukar, 1986).

II.2.a. Biological Perspective on Millet Head Miner and *Habrobracon Hebetor*

The millet head miner is the major chronic pest of millet in the Sahel. Infestations occur annually, especially on early-planted millet. Damage can cause annual millet yield losses up to 85% in Niger if untreated (Gahukar et *al*., 1986; Nwanze and Sivakumar, 1990; Krall et *al*., 1995; Youm and Owusu, 1998). Cultural management, breeding, and pesticides are ineffective or infeasible ways to prevent yield losses from the millet head miner (Gahukar, 1989, 1990, 1992; Nwanze and Sivakumar, 1990; Baoua et *al*., 2009). Control with *H. hebetor* has emerged as the only viable and effective control strategy for the millet head miner problem. It can parasitize up to 90% of millet head miner larvae resulting in reduced grain loss from individual infested millet heads of 41% (Baoua et *al*., 2014).

Adult millet head miner moths lay their eggs on millet panicles during the panicle emergence period which usually occurs between late July and early August in Niger. Eggs hatch 3-5 days later, and larvae soon begin feeding on the millet panicle (Gahukar, 1989). Larvae chew between the rachis and flowers leaving a distinct spiral pattern and preventing grain formation. Larval development takes approximately 30 days, and then the full grown caterpillar drops to the ground and burrows to pupate (Youm et *al*., 1995). The caterpillar will remain in the ground for most of the year until it re-emerges about six weeks after rains begin (Jago, 1987). Rains can begin any time between late May and June 20th, though generally in early June. There is only one generation of millet head miner per year.

H. hebetor is a minute wasp which parasitizes many lepidopterous pests of stored grains and field crops including the millet head miner. The wasp stings the head miner, causing paralysis and stopping metamorphosis, and then lays eggs in the larva. About eight wasp larvae, feeding on the host, can develop in one host larva. The maturity process takes about 10 days from egg to adult. *H. hebetor* has been shown to naturally parasitize the millet head miner at rates ranging from 2% - 95% although this often occurs after crops have already been damaged (Gahukar, 1986; Bhatnagar, 1987, 1989; Youm and Gilstrap, 1993).

II.2.b. Previous Research on Controlling the Millet Head Miner

The millet head miner has threatened food security in Niger since the drought of 1972-1974 (Payne, 2011). Numerous studies were undertaken in the 1980s and 1990s to better understand the lifecycle and behavior of the millet head miner, to attempt to breed plants for resistance, and to identify potential natural enemies of the head miner (Guèvremont 1981, 1982, 1983; Gahukar *et* al., 1986; Bhatnagar, 1989; Gahukar, 1990; Ndoye, 1992; Youm and Gilstrap, 1993; Krall *et* al., 1995; Henzell *et al*., 1997; Youm and Owusu, 1998; Baoua *et al*. 2009). Attempts to breed plants for resistance have found little success (Henzell *et al*., 1997; Baoua *et al*. 2009). Biological control has emerged as the most attractive control solution, with *H. hebetor* being considered the natural enemy with the greatest potential (Guèvremont, 1983). Entomologists in Senegal began experimenting with refining techniques for rearing *H. hebetor* in the mid-1980's (Payne *et al*., 2011). In 1987, Youm and Gilstrap began investigating the *H. hebetor* in Niger, developing life-fertility tables of *H. hebetor* reared on head miner larvae. ICRISAT and INRAN became involved in efforts to rear *H. hebetor* in Niger in 1998 leading to several experiments that attempted to refine the release of the parasitoids. A release technique using jute bags filled with millet, rice moth larvae (feed for *H. hebetor*), and impregnated *H. hebetor* was first attempted in 1999, yielding promising results (Garba, 2000). By 2000, the scientific groundwork had been laid for an effective biological control solution, but there was still little institutional support to facilitate the transfer of the technology to farmers' fields (Payne, 2011). Payne (2011) suggests that the biological control program had slowly evolved to this point due to "sporadic, uncoordinated and insufficient funding of technology development, and neglect of human capacity building, including training and postgraduate support of scientists" (p.189).

Recent efforts to advance the biological control program have been better coordinated and funded, and as a result, the program has made significant progress towards large-scale implementation. Since 2006, the McKnight Foundation has been supporting the GIMEM (Integrated Management of Pearl Millet Head Miner) project in Niger, Mali, and Burkina Faso. The goals of this project are as follows: (i) implementing on-farm testing of the biological control system; (ii) training students, technicians, extension agents and farmers in GIMEM and other technologies; (iii) conducting further research on control of the head miner; and (iv) evaluating pearl millet varieties for resistance to the head miner (Payne, 2011).

II.2.c. Optimal Release Technique of *H. Hebetor*

Ba et *al.* (2014) formalize the current best practices for on-farm *H. hebetor* releases. The technique involves placing two mated female *H. hebetor* in a 7 cm x 10 cm jute bags filled with 200 g of millet grain, 100 g of millet flour, and 25 rice moth larvae (*C. cephalonica*). A set of 15 jute bags should be scattered around a village's farms, with 3 bags placed on a centrally-located farm and 3 bags placed on farms in each cardinal direction (N, S, E, W) from the central farm. Typical villages have a diameter of 1 km, and bags can be placed about 500 m from the central farm. Bags should be suspended from the ceilings of straw granaries, or if straw granaries are not available, bags can be covered with calabashes and hung from trees or tall wooden stakes. Calabashes protect bags from rain and wind. Parasitoids reproduce and multiply within bags, and their offspring escape through the jute mesh and disperse. A new generation emerges after 7-14 days, with the average development time around 12 days. One bag has been shown to generate 57-71 parasitoids (Ba et *al*., 2014). If 15 bags are utilized, approximately 1000 parasitoids can be released within 12 days, and the population would be expected to build to over one million within four weeks. *H. hebetor* can travel up to 5 km from release point and parasitize 90% of millet head miner larvae.

II.3. Key Institutions

This section describes institutions that have been involved and will continue to be involved in the implementation of the proposed biological control industry.

II.3.a. International Crop Research Institute for the Semi-Arid Tropics

The International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) is an international non-profit research organization dedicated to agricultural development. It is the lead institution for the overarching project to which this study contributes (The Biological Control of the Millet Head Miner in Niger and Senegal). The ICRISAT Sahelian Center was started in 1981 with the mission of improving food and nutrition security, reducing poverty, and protecting the environment in poor rural areas of Niger (ICRISAT, 2013). ICRISAT has been involved with research on the biological control of the millet head miner since 1998.

II.3.b. Institut National de la Recherche Agronomqiue du Niger (INRAN)

Institut National de la Recherche Agronomqiue du Niger (INRAN) is Niger's government-funded national agricultural and natural resources research institution and is one of the two lead institutions (with ICRISAT) that is researching the biological control of the millet head miner. Its mission is to improve rural livelihoods and influence national agricultural policy.

II.3.c. Farmer Federations

Nigerien farmer federations are organizations that support farmers and are expected to play an important role in the distribution of *H. hebetor*. Federations generally provide farmers with agricultural inputs, financial services, and farm consultation. Several farmer federations are located throughout Niger, corresponding to the country's administrative regions. In Niger's major millet-growing regions, federations include Mooriben (Dosso and Tillaberi), FUMA Gaskiya (Maradi), Ider (Tahoua), and FUBI (Zinder). Federations are comprised of unions, which usually correspond to administrative subdivisions called communes. Each union is comprised of many village-level groups referred to as "groupements." Farmers pay member fees to join a groupement, groupements pay member fees to a union, and unions pay member fees to the federation.

Mooriben and FUMA Gaskiya are the focus of the remainder of this study, as they were the federations chosen to host the launch of pilot-tested *H. hebetor* businesses in 2015. Mooriben translates to "misery is over" in the Zarma language. The federation is subdivided into 30 farmer unions, accounting for over 56,000 members split between over 1,500 groupements in more than 700 villages (Mooriben, 2014). To improve the food security of rain-fed farmers, the federation provides a suite of services related to agricultural production, micro-finance, humanitarian assistance, network capacity, and communication. Priorities include improving access to inputs, networks, markets, storage facilities, credit, savings, and social safety nets. At the executive level, the federation is responsible for education, monitoring and evaluation, conducting research, coordinating early warning alerts, and advocacy. Unions are responsible for conducting training, operating agricultural input shops, establishing savings and credit programs, building and supervising cereal banks, and managing warehouse receipts. Groupement leaders are responsible for disseminating information to members, mobilizing savings and credit programs, promoting literacy, facilitating warrantage, organizing agricultural input distribution, managing collective fields, and operating cereal banks.

FUMA (Federation of Unions of producers in Maradi) Gaskiya is a farmer federation composed of 17 unions with 325 groupements, and around 12,000 members. The federation's goal is to contribute to the economic, social, cultural, and technological development of farmer producer groups in the rural areas of the Maradi region of Niger. Activities include the promotion of high-yield crops, assistance in marketing crops, improving technology accessibility, and diversifying agricultural production systems. The organization is supported by fees from its member unions, and it regularly collaborates with agricultural research institutions.

Similar to Mooriben, FUMA Gaskiya operates input stores, farmer field schools, credit programs, and storage facilities at the union level.

Input shops are crucial to this study because they are likely to play a role in the distribution of *H. hebetor* technology. Input shops are one-stop service centers that provide members with agricultural inputs and advice on their proper use. The shops take advantage of bulk sales and collective purchases to allow farmers to contribute to the purchase of inputs according to their financial resources. Shops have increased demand for fertilizer, seeds, plant health products, and livestock products (Mooriben, 2012). Other accomplishments include the provision of input quality control and the widespread improvement of farmers' fertilizer application knowledge.

II.3.d. *H. Hebetor* Business Pilot-Test of 2015

Five farmer unions and one existing agricultural input company were chosen by ICRISAT and INRAN to launch *H. hebetor* businesses as a pilot-test in 2015. Figure 3 provides a map of these business locations. Pilot businesses were provided with basic start-up equipment and trained to rear and release *H. hebetor*. Each business sent 2 or 3 people to INRAN's station in Maradi to have a week-long training session where they learned to multiply insects, prepare bags, sensitize farmers to insects, place bags in fields, and evaluate success. The goal of the project was to establish private businesses with the capacity to sell bags in 2015 and subsequent years. Table 1 displays the number of bags sold by respective businesses during the first year of production and the purchasers of those bags. The vast majority of bags were sold to projects and NGOs, while very few bags were sold to farmers. Leaders of the biological control program in Niger have voiced concerns that project and NGO purchases may not be sustainable purchasing methods if organizations do not make long-term commitments to sponsor *H. hebetor* provisions for villages. Villagers may be less likely to purchase *H. hebetor* if they become accustomed to receiving the product for free. If business planners and owners believe that targeting villages, rather than organizations, is vital to the sustainability of the market, it will be useful to investigate the feasibility of villagers to cooperatively afford beneficial insect bags. Our business feasibility assessment will explore the economic feasibility of cooperative purchases.

Multiple workers from all six businesses responded to a questionnaire about their first-year experiences breeding and selling *H. hebetor*. These responses provide valuable information for business planners to consider in subsequent years of the biological control project. Five out of six businesses were able to independently rear and sell parasitoids in a timely manner after being provided with training and equipment. The one business that failed did not multiply insects fast enough, resulting in the unavailability of parasitoids at the critical time in the millet head miner's development. However, this business was able to secure parasitoids from one of the successful businesses in order to fulfill their customer obligations. Some other problems faced by businesses included insufficient equipment and failure in rearing parasitoids. These problems can be addressed through improved training, and workers sound optimistic about improving their businesses and selling many more insect bags. Some of these issues are considered in more detail in different sections throughout the remainder of the paper.

Figure 3: Locations of Pilot Businesses across Niger

Table 1: *H. Hebetor* Bag Sales by Pilot Businesses

Name of Union (Region)	Localities	Number of released bags produced and sold to farmers	Number of released bags produced sold to projects and NGO
Harey Ban (Tillaberi)	Téra	180	643
Aiki Lafia (Maradi)	Sarkin Bindiga	15	330
Foussaha (Tahoua)	Guidan Ider	0	225
Dubara (Maradi)	Serkin Hausa	0	250
F**amey (Dosso)**	Dan Tchandou	0	0
Sahel Bio (Maradi)	Maradi	0	3686
Total		**195**	**5134**
		5329	

Chapter III. – Conceptual Issues and Framework____

This section describes concepts relevant to the two central analyses of this study, an economic feasibility assessment for *H. hebetor* businesses and an econometric modelling of the factors that affect willingness-to-pay for *H. hebetor*. Concepts include public goods, cooperative clubs, business cost coverage, contingent valuation, willingness-to-pay theory, and factors that affect willingness-to-pay.

III.1. Public Goods and Market Failure

A free-rider is a person who receives the benefit of a good but avoids paying for it (Mankiw, 2012). Free-riding occurs in the presence of a public good which, by definition, is a good that cannot be excluded from consumers and can be used without reducing its availability to other consumers. *H. Hebetor* is a privately purchased good that exhibits the characteristics of a public good. The parasitoids can spread up to 5 km from their release point, and they produce positive externalities for neighbors since every farmer within a certain radius of the release will benefit from the pest control. Economic theory suggests that farmers will have the incentive to under-contribute in this market, causing businesses to produce less than optimal quantities of beneficial insects. Samuelson (1954) noted that certain goods, after initial purchase, can be consumed by many consumers who face no additional cost. Rational consumers, trying to maximize utility, will gravitate toward least cost options. When consumers face no cost, price is essentially zero. Perfectly competitive businesses will produce a quantity of goods such that price equals marginal cost, but if many consumers face no cost, businesses face incentivizes to produce a suboptimal quantity. Thus, if producers and consumers operate under assumptions posed by standard economic theory, free-riding could jeopardize the sustainability of market supply.

III.2. Club Theory: Overcoming Free-Riding

The key to overcoming free-riding is to curb individual incentives to under-contribute. In the absence of government intervention, this usually requires cooperation among beneficiaries. A club is a voluntary group that sets up an incentive structure in order to reap mutual benefits from sharing the costs of public good provision. In a study on climate change cooperation, Nordhaus (2015) designates the following conditions for a successful club:

(i) that there is a public-good-type resource that can be shared

(ii) that the cooperative arrangement, including the dues, is beneficial for each of the members

(iii) that non-members can be excluded or penalized at relatively low cost to members

(iv) that the membership is stable in the sense that no one wants to leave.

Knowing that the first condition is true of beneficial insects, the second condition is the critical factor for cooperative arrangements, given the market context. If all farmers feel that they benefit from a cooperative purchase, there should be stable demand for parasitoids. If Nordhaus's second condition holds, then the third condition, that non-members can be excluded or penalized, may not be important given the uniqueness of the social context. The prospective market is comprised of subsistence farmers who live in village units that exhibit a culture of mutual cooperation, so it is unlikely that villagers would want to or need to develop a precedent of ostracizing in order to maintain an effective club arrangement.

Meeting the second condition also improves the likelihood that the fourth condition is met. Sustaining farmers' interest in contributing to cooperative purchases depends on many factors, but the most critical factor is the ability of cooperative arrangements to produce mutual net benefits for all farmers. If the cooperative arrangement is economically beneficial for all involved, farmers will be less likely to defect. However, economic rationality does not guarantee that farmers will contribute to a cooperative purchase in every year with a high risk of millet head miner infestation. It may be most difficult to convince farmers to make contributions to a village's first purchase, due to product unfamiliarity, and to purchases in the distant future, if farmers forget about the pest problem after years of successful pest control. Businesses, public institutions, and the government must play an active role in sensitizing farmers to the product and promoting annual awareness of the product over time. If promoted effectively, the product is expected to generate widespread demand.

The portion of this study devoted to the problem of free-riding will attempt to demonstrate that Nordhaus's second condition can be met for a cooperative purchasing arrangement. In theory, farmers benefit from purchasing the *H. hebetor* if they pay a price below the value of lost millet yields that they can expect to regain by releasing the beneficial insects and the beneficial insects are cheaper than alternative controls (of which there are none). One might think of this value as the "true value" of the parasitoid. Farmers might not be willing to pay this value because they do not accurately estimate the value of damage to their crops from a single pest. It will also be useful to then examine farmers' "perceived value" of the parasitoid which is available through a farmer survey. A survey question concerning willingness-to-pay asks farmers how much they would individually pay for beneficial insects if the insects would eliminate their millet losses from the millet head miner. The question indicates nothing about the public good nature of the *H. hebetor* or that villages would be best served to purchase the bags cooperatively, so in theory, the question should elicit responses that closely resemble the true value of the parasitoid to each individual farmer. It will be useful for researchers to establish benchmark estimates of the true and perceived value of *H. hebetor* in order to show that all farmers could benefit from a variety of purchasing arrangements.

III.3. Covering Costs

If cooperative purchasing agreements can produce mutually beneficial outcomes for all farmers, then demand for parasitoids is expected to be stable and widespread, and building a successful market for parasitoids will depend on business's ability to generate adequate revenue relative to costs. In this study, it is assumed that in the short run, businesses must generate revenue greater than the total costs of production in order to justify continued operation. This criterion for continued operation is contrary to the shutdown rule of microeconomic theory which states that in the short run, a firm should continue operating if revenue covers *variable* costs. This study assumes that total costs, rather than only variable costs, must be met in the short run because small businesses are unlikely willing or able to assume the risk of being unprofitable for numerous years while fixed costs are being paid down. Furthermore, it is expected that a business would not struggle to pay off total costs in the first year, as will be shown by budgeting analysis later in this paper. The most costly inputs in the business process are the rearing rooms needed for raising parasitoids and the rice moth larvae feed. These rooms represent two-thirds of total costs, but it is expected that many businesses will receive rooms for free from farmer union organizations. Even if businesses pay market rental rates for rooms, they are expected to be profitable in the short run, assuming that they charge modest prices for products. The business feasibility assessment will help businesses understand how many *H. hebetor* bags they need to sell to cover their costs and justify the investment in starting a business.

It should be noted that the business feasibility assessment assumes that businesses are able to fund initial start-up costs, which is not plausible in all likelihood because the people who run businesses are likely to be farmers or low wage workers who do not have funding readily available. Research institutions plan to provide businesses with start-up equipment, as they did for pilot businesses in 2015. The reason for assuming that businesses pay their own initial costs is to generate conservative profit estimates. Also, the assumption provides some sense of the costs businesses will presumably pay in the future when they need to replace their equipment after they are established and financially independent.

III.4. Contingent Valuation: Willingness-to-Pay for Beneficial Insects

The business feasibility assessment and econometric model are both influenced by a contingent valuation-style survey question. This study uses the contingent valuation method (CVM) in a manner that is atypical of most CVM studies. CVM studies generally use surveys to elicit the value of nonmarket public goods like governmental or environmental services. This study uses the same basic approach, but the good under consideration is not a "nonmarket" good but a "not-yet-marketed" good. In this way, the study is similar to a customer survey that gauges consumer interest in a product prior to its market introduction. Still, the survey question is rooted in the CVM concept of deriving economic value from directly stated preferences. Survey responses to an open-ended willingness-to-pay question represent farmers' preferences and can be analyzed as if they were choices made by consumers in a real market. Economic value is derived from consumer's choices in this hypothetical market scenario.

Willingness-to-pay was elicited through an open-ended question preceded by a brief description of the beneficial insect technology and worded as follows:

> "The millet head miner is an insect that damages the head of millet crops. *H. hebetor* is a beneficial insect that helps to control the millet head miner. It comes in a small bag and is placed in your field. How much would you be willing to pay for *H. hebetor* if it eliminated your losses for the year from the millet head miner?"

Farmers were also shown a picture of the millet head miner. The question was imbedded in a multipurpose survey comprised of questions about farmer demographics, crop production statistics, pest management issues, and knowledge of beneficial insects. A single open-ended question was chosen as opposed to a more complicated choice experiment-style questionnaire, in order to keep the survey short and simple. There are many critics of open-ended contingent valuation questions, but these criticisms are not believed to hinder the applicability of the method for this particular study.

Some critics argue that it is difficult for respondents to deduce a dollar value that accurately represents the value of a good. However, this criticism is more relevant in the case of goods that have no market precedent, like an ecosystem service, or when the hypothetical payment occurs through an indirect transfer, like a tax. The question posed in this survey concerns the purchase of a good that would be bought directly with cash from a dealer just like any other farm input.

Still, there are inherent flaws in an open-ended valuation of an easily understood, marketed product. Consumers may not have incentive to reveal their true willingness-to-pay, finding reason to either understate or overstate their willingness-to-pay. They may understate willingness-to-pay in a collaborative attempt to keep prices low (Nessim and Dodge, 1995). They may overstate willingness-to-pay in order to not appear stingy, a phenomenon sometimes referred to as prestige effect (Holden and Nagle, 2002). There are various reasons to believe that these concerns will not be problematic for obtaining willingness-to-pay information that is applicable to the purposes of this study. Recall that the two purposes for estimating willingness-to-pay in this study are to inform pricing scenarios for a business and to perform a regression that estimates the impact of farmer characteristics on willingness-to-pay. With regards to the budgeting analysis, overstatements of willingness-to-pay are of the most concern, because they may cause businesses to overestimate potential profits. However, an inherent goal of businesses is to include a high percentage of village farmers in cooperative purchasing arrangements, which requires keeping per-household prices exceptionally low. Farmers are expected to pay less than their indicated willingness-to-pay value, so survey overstatements are unlikely to mislead business feasibility results which utilize low per-household prices.

The open-ended question is also believed to generate valid information for employing econometric analysis. Farmers with severely limited income should have a narrow range of possible responses, so their valuations are not expected be overly misleading. A large enough sample size is expected to overcome small biases such that the model yields relevant information about the relative importance of farmer characteristics in predicting willingness-to-pay.

III.5. Economic Interpretation of Willingness-to-Pay

The economic meaning of a farmer's stated willingness-to-pay can be better understood using the economic concept of utility. Since farmers in Niger grow millet for purposes of both home-consumption and sales, they can be thought of as either utility-maximizers or profit-maximizers, but this study will defer to utility terminology since the majority of millet grown by subsistence farmers in Niger is grown for home consumption. Economic theory predicts that utility-maximizing farmers will decide to buy beneficial insects if the purchase improves their utility, and the extent to which they are willing-to-pay for the technology should be equal to the value of millet yield losses that they can expect to recover by using beneficial insects. This logic assumes that farmers are rational economic agents who make efficient use of all given information to make economic forecasts, but a more realistic analysis considers that farmers have bounded rationality such that they cannot accurately process information even if the information is completely available. Farmers cannot perfectly track and value the damage done by a single type of pest over broad spans of land, and they also might not have complete trust in a technology that is completely new to them. In effect, willingness-to-pay data gathered from a survey will not perfectly reflect the benefits that farmers stand to gain from using the new technology. These potential benefits might largely inform a farmer's stated willingness-to-pay, but willingness-to-pay will also be a function of other farmer characteristics. Herein lies an impetus for estimating the factors that affect willingness-to-pay. A better understanding of the factors that affect willingness-to-pay could help researchers understand farmers who are less likely to pay for beneficial insects and subsequently develop strategies to encourage participation in cooperative purchases.

III.6. Lessons from Technology Adoption Studies

The econometric model of the factors that affect willingness-to-pay for beneficial insects is informed by empirical findings from agricultural technology adoption studies in developing countries. Adoption models are an appropriate reference for our willingness-to-pay model because the factors that affect farmer willingness-to-pay for technology are expected to be similar to the factors that affect farmer adoption of technology. Also, there is richer and more developed literature on adoption studies as related to agricultural technologies in developing countries. We are making the assumption that the theoretical underpinnings of adoption models are also appropriate for our modelling of willingness-to-pay.

Feder, Just, and Zilberman (1985) review theoretical and empirical work on key explanatory factors of agricultural technology adoption behavior in developing countries. Their empirical review is organized by categories of factors that have been shown to affect adoption. Categories include farm size, risk and uncertainty, human capital, labor availability, credit constraints, land tenure, and supply constraints. Some of these categories are easy to measure, and some are not so straightforward. Over the course of their extensive review, Feder, Just, and Zilberman (1985) implicate the following specific variables as having empirically supported relationships with adoption: farm size, whether a farmer was visited by extension agents, whether farmers attended extension agent demonstrations, education, age, rural labor supply, access to credit, income, and land tenure status. This list is by no means exhaustive, but it gives a sense of the type of variables commonly examined in adoption models.

Several empirical studies have specifically examined factors affecting pest management technology adoption decisions by farmers (Napit et *al*., 1988; Fernandez-Cornejo et *al*., 1994; Tjornhom et *al*., 1997; Bonabana-Wabbi, 2002; Victoria et *al*., 2007). Studies generally identify a variety of socioeconomic and agronomic factors that affect adoption, which vary depending on the location and type of technology. Bonabana-Wabbi (2002) generalizes four categories of factors that are likely to be relevant to IPM technology adoption. These include *market forces* (e.g. availability of labor, farm size, and expected benefits level), *social factors* (e.g. age, education, and gender), *management factors* (e.g. organization membership and credit capability), and *institutional/technology delivery mechanisms* (e.g. access to extension services and pest management training). Knowledge from previous research was reconciled with intuition and available data to reveal a pool of potential factors that could affect willingness-to-pay for beneficial insects.

Chapter IV. – Methods

IV.1. *H. Hebetor* Business Feasibility Assessment

A business feasibility assessment is a methodical, documented process of investigating a business opportunity to determine its viability and potential given the practical realities of the environment in which it will be implemented. Elements of a business feasibility assessment vary by business type and market opportunities. This feasibility assessment will be organized into sections that focus on seven components: operations, profitability, affordability, risk, worker benefits, farmer benefits, and total market potential. The operational section describes the timeline and equipment needed for rearing and selling *H. hebetor*. The profitability section presents enterprise budgets for a single business based on varying prices and sale quantities. The affordability section investigates how per-household contribution to cooperative purchases could vary by bag price and village size and how these contributions compare to farmers' WTP. The risk section highlights several potential business risks and suggests ways in which businesses might adapt to these risks. The worker benefits section translates labor costs into a daily wage which is compared to the daily wage of comparable employment. The farmer benefits section briefly documents the estimated benefits of the biological control for farmers, because researchers would like to ensure that farmers who purchase *H. hebetor* based on perceived need are indeed benefitting from such a purchase. The market potential component examines the potential geographic scope of the entire market, which has important consequences for market planners and individual businesses.

This study will provide a wide range of information that can be used by researchers and prospective businesses to appraise individual business opportunities and market organization as a whole. In total, the feasibility assessment will shed light on the following questions:

(1) What are the necessary procedures for operating an *H. hebetor* business?

(2) What pieces of equipment does a business need, and what are the associated costs?

(3) How many *H. hebetor* bags must be sold for a business to cover its costs?

(4) How do profits vary based on price and demand?

(5) What is the minimum product price needed to cover costs at a given output?

(6) What pricing options are available for businesses based on profits and consumer willingness-to-pay?

(7) How does per-household contribution to a cooperative purchasing scheme vary based on combinations of village size and product price?

(8) Which business risks are most concerning, and how can these risks be managed?

(9) Will workers earn a fair wage?

(10) What is the real value of *H. hebetor* to farmers, and how does this compare with their perceived value?

(11) What factors should inform business location?

(12) How many businesses are needed to satisfy widespread demand, and what are important market organization considerations?

IV.2. Econometric Model

The objective of the econometric study is to estimate the effect of farmer characteristics on willingness-to-pay for *H. hebetor*.

IV.2.a. Data

Data was collected from 400 randomly-selected millet farmers from 40 randomly-selected villages in Niger during the summer of 2015. The survey sample is divided evenly between farmers in the Tillaberri and Maradi regions of Niger. These two regions were chosen for multiple reasons. First and foremost, both regions are heavily affected by the millet head miner and are believed to be representative of other millet-growing regions in Niger. Also, researchers wanted to survey two different regions to ensure a more varied sample and to allow for a comparison between a region where many farmers have been introduced to the millet head miner (Maradi) and one where farmers are less familiar with the biological control (Tillaberri). The survey team agreed that the survey sample would consist of 10 households in each of 40 villages, for a total of 400 households. Villages were randomly selected from a village-level map provided by ICRISAT. Two enumerators were assigned to administer surveys in Maradi, and two were assigned to Tillaberri. The survey was designed with the assistance of the ICRISAT and INRAN. Farmers were asked a variety of questions about demographics, farm production, input costs, pest severity, pest management, and willingness-to-pay for parasitoids. Willingness-to-pay was elicited through an open-ended question preceded by a brief description of the beneficial insect technology**.**

IV.2.b. Variables

Willingness-to-pay is hypothesized to be a function of farm and farmer characteristics including age, level of education, number of domesticated animals, quantity of millet produced quantity, pest severity, farmer organization status, and administrative region. Table 2 provides a complete description of variables, and section IV.2.e later explains the intuition behind chosen variables.

Table 2: Description of Variables Used

Variable	**Type**	**Description**
WTP	Continuous	Willingness-to-pay for beneficial insects if they were to eliminate annual damages to millet plants from the millet head miner
Age	Continuous	Age in years
NoEdu	Binary	Whether a farmer's highest level of education attained is no education: 0 = no, 1 = yes
Animalswt	Continuous	Combined number of cows, sheep, goats, and donkeys, weighted by value; Sheep, goats, and donkeys are respectively considered 1/5, 1/10, and 1/4 the value of cows.[a]
MilProd	Continuous	Kilograms of millet produced last year
Sev	Binary	Reported level of damage caused by millet head miner; 0 = low or medium, 1 = high[b]
Farmorg	Binary	Whether a farmer is a member of a farmer groupement; 0 = no, 1 = yes
Hebetor	Binary	Whether a farmer has previously received *H. hebetor*; 0 = no, 1 = yes

[a] The weighted animal index consists of cows, donkeys, sheep, and goats. Weights are determined by approximate market prices (Ministry of Livestock Director of Statistics, 2016). A donkey, a sheep, and a goat are respectively considered 1/4, 1/5, and 1/10 the value of a cow.
[b] Low and medium levels of reported millet head miner damage are combined to form the opposing binary to "high" damage because survey farmers reported both of these levels significantly less than high levels.

Gender was not included in the model because almost the entire sample is composed of men. The weighted value of animals was the best available proxy for farmer wealth. The key variables under examination indicate whether or not a farmer belongs to a farmer organization and whether a farmer has previously received *H. hebetor*. These key variables are important because they have the potential to inform interventions that could encourage greater stability among the demand base for the beneficial insect market.

IV.2.c. Summary Statistics

Table 3 includes survey summary statistics for the variables used in the econometric model as well as other variables that provide more background about the sample of farmers. The original survey collected data on 400 farmers, but for the purposes of econometric analysis, the sample size was trimmed to 359 due to outliers and missing data. Farmers were split relatively evenly between the Maradi region (182) and the Tillaberi region (177). The average age of farmers was 49.8. The vast majority of farmers had no schooling (79.0%), and only one farmer indicated that he had received above a middle school education. This result is consistent with the mean country-wide years of schooling (1.5) as reported by the United Nations (UNDP, 2015). Median area of millet cultivation was 4.3 hectares, and median annual millet production was 900 kg. Median millet yield was 217.9 kg/hectare. This is significantly lower than the average millet yield observed in Niger of 407.5 (Leblois et *al*., 2014), but it is not uncommon for Nigerien farmers with limited inputs to have yields lower than 400.

Table 3: Summary Statistics

	Mean ± SD	Median	Min	Max		
Age	49.8 ± 14.7	50	21	85	**Highest Education**	No School: 79.0% Primary School: 15.7% Middle School: 5.0% High School: 0.3% University: 0%
Household Size	13.4 ± 7.9	12	2	53	**Marriage Status**	Single: 0.3% Married: 99.1% Widowed: 0.6%
Household Size (Over 10 years old)	8.0 ± 5.3	7	2	37	**Number of Spouses**	0: 0.3% 1: 54.0% 2: 38.3% 3: 7.4%
Animals (value weighted)*	2.6 ± 4.1	1.2	0	28	**Are you in a Farmer Organization?**	No: 85.0% Yes: 15.0%
Millet Area Cultivated (ha)	6.2 ± 5.8	4.3	0.5	38	**Severity of Millet Head Miner Damage**	Low: 0.8% Medium: 10.3% High: 88.8%
Millet Production (kg)	1429.4 ± 1510.4	900	25	9120	**Are you familiar with biological control?**	No: 51.8% Yes: 48.2%
Millet Yield per Hectare (kg)	269.7 ± 218.7	217.9	22.4	1600	**Have you ever heard of the *H. hebetor*?**	No: 52.5% Yes: 47.5%

Willingness-to-pay for *H. hebetor*	$4.35 ± $5.04	$1.67	$0.09	$25.04	**Have you ever received the *H. hebetor*?**	No: 81.3% Yes: 18.7%
					Did the *H. hebetor* limit damage from the millet head miner (if you received *H. hebetor*)?	No: 25.4% Yes: 74.6%

* The weighted animal index consists of cows, donkeys, sheep, and goats. Weights are determined by approximate market prices (Ministry of Livestock Director of Statistics, 2016). A donkey, a sheep, and a goat are respectively considered 1/4, 1/5, and 1/10 the value of a cow.
* Note that summary statistics are calculated after outliers are removed for the purpose of the econometric analysis that comes later in this paper.

Over 88% of farmers reported severe damage from the millet head miner. This is a significantly higher percentage than was reported for any other insect on the survey. No farmers indicated that they use pesticides to control the millet head miner. About 47% farmers reported being familiar with *H. hebetor*, and of these farmers, over 95% lived in the Maradi region. Only 67 farmers claimed to have previously received *H. hebetor*, presumably from an NGO or research experiment, and all but two of these farmers lived in Maradi. Farmers reported a median willingness to pay of $1.67 for *H. hebetor* if it could entirely eliminate millet yield losses from the millet head miner, which is similar to findings from previous informal conversations with farmers (Ba et *al*., 2013).

IV.2.d. Empirical Model

The proposed linear model is formalized as such:

$$WTP = \beta_0 + \beta_{1*}(Age) + \beta_{2*}(NoEdu) + \beta_{3*}(Animals) + \beta_{4*}(MilProd) + \beta_{5*}(Severity) + \beta_{6*}(FarmOrg) + \beta_{7*}(Hebetor) + \mu$$

The dependent variable is continuous, so the appropriate estimation method is ordinary least squares (OLS) provided that the Gauss-Markov properties are satisfied (Woolridge, 2015).

The variable representing whether a farmer had previously received *H. hebetor* has a very high correlation with region, and limited data prevents our ability to isolate the effects of regional differences or exposure to *H. hebetor*. Splitting the sample by region is considered too much of a handicap to sample size. We will keep the exposure variable in the regression equation, noting that it may represent regional differences in addition to exposure. Another complicating factor of the *H. hebetor* exposure variable is that only 18% of farmers have previously received the parasitoid, and of this 18%, about 25% said that the parasitoid was not effective in limiting millet losses. We know that in the past decade NGOs have been giving away some parasitoids for free, and sometimes the parasitoids fail to limit millet yield losses because they are delivered to farmers too late in the season. So it is likely that some farmers have negative opinions on the parasitoids' effectiveness. Also, there is the potential that farmers who have received the parasitoid are willing to pay less because they are accustomed to receiving the insect for free. In sum, there are various reasons why the relationship between exposure to *H. hebetor* and willingness-to-pay relationship may not have a straightforward interpretation.

IV.2.e. Expectations

The following list briefly explains the a priori hypotheses for the independent variables' signs in the model and the rationale behind including the chosen variables in this model.

1) *Age* - Increases in age are expected to lower willingness-to-pay because older farmers are thought to be more averse to newer technologies while younger farmers are more open-minded. This hypothesis is solely based on intuition given that previous studies indicate that there is not a consensus on the direction of the impact of age on adoption (Asiedu-Darko, 2014).

2) *NoEdu* - Farmers with no formal education are expected to be willing to pay less for

parasitoids because they have lesser capacity to assess the merits of the *H. hebetor*. The base group represents farmers whose highest level of educational attainment is at least primary schooling.

3) *Animals* - Owning more animals is expected to predict greater willingness-to-pay. This variable is used as a proxy for wealth, as there is no better indicator of wealth in the available survey data. Greater wealth implies greater capacity to purchase the new technology.

4) *MilProd* - Farmers who produce more millet are expected to express higher willingness-to-pay because they are likely to have greater expected levels of benefits from addressing a pest problem.

5) *Sev* - Higher severity of millet head miner damage is expected to predict greater willingness-to-pay because a worse pest problem is believed to motivate a greater need for preventative action.

6) *FarmOrg* - Being a member of a farmer organization is expected to predict greater willingness-to-pay because of network effects. A social network encourages sharing information which can help farmers overcome informational constraints and learn the pest control's merit.

7) *Hebetor* - Previous exposure to *H. hebetor* is expected to predict greater willingness-to-pay for *H. hebetor* because farmers are believed to have more trust in a new technology that they have experienced firsthand.

Chapter V. – Business Feasibility Results

V.1. Operations

This section of the feasibility assessment serves as a basic guide to operating an *H. hebetor* business. First, it documents time-specific considerations for producing the product in a timely manner. Next, it provides an overview of costs, quantities, and considerations for each necessary business input. This input information is used in the next subsection's enterprise budget.

V.1.a. Rearing Procedures

Rearing *H. hebetor* is a relatively simple process that requires careful attention to time-specific variables. In order to minimize millet yield losses from the millet head miner, it is crucial for farmers to release *H. hebetor* within a relatively short window of opportunity. A late release will fail to prevent yield losses, as the millet head miner can do immense damage to the millet crop in just one week. An early release may threaten *H. hebetor* from maintaining a robust population in the wild, although it is safer for farmers to tend toward an early release because during the rainy season, the *H. hebetor* should have sufficient hosts to maintain its population prior to its opportunity to feed on millet head miner larvae.

Considering the importance of release timing, businesses must be ready to supply an adequate number of *H. hebetor*-filled bags within a precise timeframe. The process of rearing a sufficient number of parasitoids by a target date requires that businesses account for time-dependent variables of the millet-growing season and the pest and parasitoid life cycles. Government extension agents will be instrumental in identifying villages that are at high risk for millet head miner infestation, and this information will likely influence business's decisions on the number of parasitoids to rear and the necessary timing of rearing activities.

As a practical rule of thumb, farmers will be best served to release the *H. hebetor* when millet plants begin to flower in fields. Specifically, a village should plan to release parasitoids when the first millet panicles in any villager's field begin to flower, presuming that the village is planning a village-wide coordinated release. It will be easier for farmers to rely on the plants' phenology, rather than millet head miner presence, as the guiding indicator for releasing the parasitoid because it is impractical for farmers to scout their own fields for the pest. Millet plants flower in August or early September, and the millet head miner begins damaging plants shortly after.

Businesses must be ready to prepare a large number of parasitoid bags by early August, which means that they must be multiplying large numbers of parasitoids starting in June or July. They will receive mated parasitoids from ICRISAT or INRAN in June or early July, and soon after, the multiplication process should commence. Within one week, a mated female placed in a petri dish with 25 *C. cephalonica* larvae (mixture of 3^{rd} and 4^{th} instar larvae) can produce 25-30 offspring with a sex ratio of 40% female and 60% male. A large stock of *C. cephalonica* must be multiplied in advance to serve as food for *H. hebetor* in field bags and during the *H. hebetor* rearing process. In order to secure enough rice moth larvae in a timely manner, it is recommended that mass-rearing of rice moths start around mid to late May. At this time in the year, it is infeasible to predict parasitoid demand, so as a precaution, it is advisable for businesses to first begin rearing large quantities which can be adjusted as a region's risk of infestation becomes clearer over time. INRAN and ICRISAT will provide businesses with an initial stock of millet infested with rice moth larvae in the first year, and in subsequent years, businesses will collect their own, which are simple to find in millet storage granaries.

Table 4 provides a timeline of key events related to the rearing process and the natural life cycles that inform the rearing process. Date ranges are broad to account for variation in millet growing season variables such as millet variety and locality.

Table 4: Timeline of Business Tasks amidst Natural Events

Timeline
Mid - Late May
• Businesses should begin multiplying *C. cephalonica*.
Late May - June 20
• First rains fall, and farmers immediately plant millet.
Late June - Early July
• Businesses receive mated *H. hebetor* from ICRISAT or INRAN and began mass multiplication.
Early August - Early September
• Millet begins flowering stage, and farmers should place *H. hebetor* bags in fields.
7 days after *H. hebetor* bags are placed in fields
• *H. hebetor* begin to emerge from bags and disperse in fields. They emerge over a course of two weeks.

V.1.b. Business Inputs

The entire business operation is a relatively inexpensive process that requires minimal inputs. Each input has unique considerations related to cost and use. Inputs vary in durability and re-usability, and certain inputs are bulky and do not need to be scaled. The following list provides an overview of important considerations for each input.

1. Rearing Rooms –

<u>Description</u>: Two small rooms, made of either clay or concrete, are sufficient for rearing *C. cephalonica* and *H. hebetor*. One room is for rearing *C. cephalonica*, and one is for

rearing *H. hebetor*. Separate rooms are needed because *H. hebetor* can sometimes escape from their confines and kill *C. cephalonica*. Rooms will not require climate control. Renting a room costs $8.35 – $16.70 per month, depending on the location. Although the entire rearing and selling process lasts approximately 3 months, it is in the best interest of businesses to continue renting rooms for the entire year so that consumers become accustomed to business locations. Rooms in larger cities are generally more expensive than in rural areas. A room is potentially the most expensive input in the entire business process, but there are also situations in which rooms are essentially costless for business owners. For example, in the summer of 2015, the owners of the pilot business in Tera were able to secure a free-of-charge room due to their association with the local farmers' union. It is difficult to gauge how common this practice will be, but for the purpose of estimating an upper bound estimate, the input budget will consider a single room to cost $16.70/month. The risk analysis in section V.3.a will take note of how profits increase if rooms are costless.

Price: $16.70/month per room

Quantity: Two rooms

Duration: 12 months/year

2. Labor –

Description: All pilot businesses decided to pay workers 10% of bag revenue which was equivalent to $0.33/bag at a price of $3.34/bag. Workers decide how to split this value among themselves. The price was conceived by Sahel Bio, a private agricultural input seller that has previous experience selling *H. hebetor* bags in the Maradi region. This figure will be used in the input budget, although different bag price scenarios will be considered in Section IV.4.

Price: $0.33/sold bag

Quantity Required: A single worker can operate the business in May and June. The business may need 1-3 additional workers from July-September for the mass multiplication and sale of *H. hebetor*.

3. Large Plastic Bucket –

Description: This bucket is used as a container for the mass-rearing of *C. cephalonica*.

Price: $5.01/bucket

Quantity Required: A single bucket can raise enough larvae to meet the *H. hebetor* bag demands of 13 villages. .

Duration of use: 5 years

4. Small Plastic Bucket –

Description: The small bucket is used for monitoring *C. cephalonica*. It is easier to assess the size of the larvae in this bucket rather than in the large bucket because the small bucket can be easily transported outside to make use of natural light. The large bucket is also too deep for inspecting the *C. cephalonica* population, and it is best to leave large buckets covered in order to prevent moth escape and the interruption of the moths' natural cycles. An additional use of the small bucket is to generate sufficient rice moth larvae to facilitate the initial breeding of *H. hebetor* in petri dishes.

Price: $2.09/bucket

Quantity Required: It is preferable to have 1 small bucket for every 1 large bucket.

Duration of use: 5 years

5. Mating Cage –

Description: *H. hebetor* are transferred to mating cages after they are bred in petri dishes. Cages consist of a bucket, a glass top, a muslin cloth, and a small glass bottle. The cage has no industry standard. It should be assembled by business owners.

Price: $5.01/cage

Quantity required: As a simple rule, a business should buy 1 mating cage for each large bucket used.

Duration of use: Every component lasts 5 years with the exception of the muslin cloth which lasts about 3 years.

6. Aspirator –

Description: Aspirators are used to transfer *H. hebetor* from petri dish to mating cage.

Price: $2.50/aspirator

Quantity: 2 per business

Duration of use: 5 years

7. Jute bags –

Description: *H. hebetor* are placed in fields inside of jute bags. Scientists recommend using 7 cm x 10 cm bags. These can be created from large sheets of jute bought in the marketplace. Pilot businesses were given two prototype bags that could be tailored to make additional bags.

Price: $0.25/bag

Quantity: 15 (7 x 10 cm) bags/village

Duration of use: Must be replaced annually.

8. Petri Dishes –

Description: Petri dishes are containers for birthing *H. hebetor*. As a simple convention, the input budget assumes that in order to safely maintain a sufficient level of *H. hebetor*, a business should purchase approximately 1 petri dish for every 25 jute bags that they plan to sell.

Price: $0.42/dish

Quantity: 1 dish for every 25 jute bags

Duration of use: 5 years

9. Cotton -

Description: Cotton is hung inside the mating cage. It is soaked in the honey or sugar that is used as food for the adult *H. hebetor*.

Price: $2.50/bag

Quantity: 1 small package

Duration of use: 1 year

10. Honey/Sugar –

Description: Honey or sugar is used to feed the adult *H. hebetor* inside a mating cage.

Price: $1.67/jar

Quantity: 1 jar

Duration of use: 1 year

11. Millet Mix for 1 Large Bucket -

Description: This millet mix serves as food for *C. Cephalonica* during its rearing.

Price: $0.42/kg of millet flour/grain; Millet mix for a large bucket totals approximately $5.78.

Quantity: 10 kg of millet grain and 3.75 kg of millet flour per large bucket

Duration of use: Replenished annually

12. Millet Mix for 1 Small Bucket -

Description: This millet mix serves as food for *C. Cephalonica* during its rearing.

Price: $0.42/kg of millet flour/grain; Millet mix for a small bucket totals approximately $1.92.

Quantity: 3.33 kg of millet grain and 1.25 kg of millet flour per small bucket (1/3 of mix needed for a big bucket)

Duration of use: Replenished annually

13. Millet Mix for Jute Bags -

Description: This millet mix serves as food for *C. Cephalonica* placed in farmers' fields.

Price: $0.42/kg of millet flour/grain; A single bag of millet mix for jute bags costs $0.03.

Quantity: 1 bag requires 50 g of millet grain and 30 g of millet flour

Duration of use: Replenished annually

14. Muslin Cloth -

Description: Muslin cloths are needed to cover large and small *C. cephalonica* rearing buckets.

Price: $0.55/yard of cloth

Quantity: 1 yard of cloth for every two large buckets

Duration of use: 3 years

15. Forceps -

Description: Forceps are used for sorting *C. cephalonica* larvae.

Price: $3.34/pair of forceps

Quantity: 5 pairs

Duration of use: 5 years

16. String -

Description: String is used to tie jute bags closed before they are transported to farmers and placed in fields.

Price: $0.25/spool

Quantity: 1 spool

Duration of use: 2 years

17. Rubber -

Description: Rubber strips are used to seal the cloth over rearing buckets.

Price: $0.25/large length

Quantity: 1 large length

Duration of use: 5 years

18. Sieve -

Description: A sieve is used to sift through millet mix to find rice moth larvae. As a simple budgeting convention, it is assumed that 1 sieve is needed for every 400 bags produced.

Price: $1.67/sieve

Quantity: 1

Duration of use: 5 years

19. Sieve Plate -

Description: A sieve plate is placed under a sieve during the sifting process in order to catch escaping grains. As a simple rule, it is assumed that 1 sieve plate is needed for every 400 bags produced.

Price: $2.50/plate

Quantity: 1

Duration of use: 5 years

20. Marketing -

Description: *H. hebetor* bags are advertised over community radio. It is very cheap to air broadcasts on community radio, and many broadcasts are subsidized by NGOs or international organizations. A marketing budget of $8.35 should be more than sufficient for one season of advertising.

Price: $8.35

Quantity: Complete marketing campaign

Duration of use: 1 Season

21. Discretionary Expense -

Description: Discretionary expenses are flexible funds purposed for contingency purchases.

Price: 10% of annual variable costs; The following inputs are considered variable costs: labor, large plastic buckets, small plastic buckets, mating cages, jute bags, petri dishes, millet mix, muslin cloth, sieves, and sieve plates.

V.1.b. Transmitting Product Information to Farmers

Information about *H. hebetor* bags is expected to be transmitted to farmers through four major channels. First, businesses can air broadcasts on community radio, which is expected to be the only marketing activity with a cost borne by businesses. Second, government extension agents can provide farmers with information on the biological control when warning villages that they have a high risk of millet head miner infestation. This is discussed in greater detail in section V.6.a. Third, businesses are encouraged to invite village representatives to observe the *H. hebetor* rearing process in order to familiarize farmers with the new technology. Fourth, information can be transmitted to farmer groups at annual farmer union meetings that are attended by farmer groupements. This will also be an opportunity to encourage villages to purchase bags as a village.

V.1.c. Categories of Buyers

Multiple categories of buyers are expected to be interested in purchasing *H. hebetor* including farmer groupements, local mayors, NGOs, and individuals. Farmer groupements are the predominant target for *H. hebetor* sales because their established relationship with farmer unions and familiarity with facilitating cooperative input purchases from farmer unions are expected to limit village free-riding potential. Not all farmers or villages belong to a farmer group network however, so *H. hebetor* markets must be open to different categories of buyers. Researchers in Niger predict that some local mayors may purchase bags for entire villages as a political gesture, and NGOs may do the same as a humanitarian gesture. These purchasing arrangements could be problematic unless purchasers are committed to the annual sustainment of *H. hebetor* supply in given villages. If villages become accustomed to third parties buying them bags, villages will be less likely to purchase bags for themselves in the event that the third parties discontinue their support. Individuals are not discouraged from purchasing bags, although these purchases could cause free-riding that jeopardizes an area’s commitment to annually sustaining an optimal level of *H. hebetor*. Individuals could also potentially purchase an inadequate supply of bags if they decide to purchase less than the prescribed 15 bags that cover a circular area with a 5 km radius. Researchers do not know how the effective radius of the technology scales down if farmers place lower than 15 bags in fields. Regardless of the category of purchaser, businesses must provide appropriate technical information and advice to encourage the sustainment and effectiveness of pest control for a given geographic area.

V.1.d. Sale and Transportation

INRAN and ICRISAT expect that village representatives will travel to central supply locations to pick up *H. hebetor* bags, as opposed to businesses transporting bags to villages. Transactions will likely take place at farmer union input shops, weekly village markets, or *H. hebetor* rearing facilities. For villages that purchase bags as a village unit, the transportation cost of retrieving bags is expected to be minimal because most villages have a representative who can pick up bags during the normal course of travel. Villages located near business locations are likely to make frequent trips to weekly markets, farmer union input shops, or central towns. Villages located far from businesses are likely to have a trader who frequently travels to central areas of business activity. If no village members regularly travel to a central business location, it will not be costly, relative to the cost of a set of *H. hebetor* bags, to pay one village member to make a single trip to a business location. Section V.3.c. examines the scenario of businesses delivering bags to villages if villages are not able to pick-up bags in a timely manner.

V.2. Profitability

An enterprise budget is a tool used to estimate the profitability associated with a single business activity. It lists all estimated expenses and income for a small unit related to the enterprise. It is difficult to define business costs associated with a small scalable unit related to the beneficial insect product due to a lack of precise information on the scalability of inputs. Specifically, it is impractical to try to define business costs for a single bag of *H. hebetor* or for the number of bags required for a single village. Such small units would bear no profit. A more practical approach is to define the costs associated with a set of *H. hebetor* bags. This set of bags reflects a level of production for which technical details of input scalability are more easily understood and for which businesses would yield profit.

The base unit for the *H. hebetor* enterprise budget will be defined as a set of bags sold to 13 villages. This is equivalent to 195 *H. hebetor* bags because each village should receive 15 bags according to entomologists' recommendations (13 x 15 = 195). A scale of 13 villages is simply a rule used to provide information on a base level of demand. The number 13 seems to be a reasonable approximation of the minimum number of sales needed to maintain a business. Furthermore, scaling-up by a factor of 13 will provide information on a wide range of feasible village sale numbers (13, 26, 39, 52, and 65).

The number 13 is chosen based on an estimated standard used at INRAN's insect-rearing laboratory. The intuition is such: *C. cephalonica* larvae, which serve as food for *H. hebetor*, are commonly bred in 47 x 44 cm plastic buckets that, if initially filled with 100 larvae, can safely produce 200 jute bags worth of larvae (5000 larvae) in 1 month. Two hundred jute bags divided by 15, the number of bags needed per village, equals 13.33, or approximately 13. In essence, a single large bucket can safely produce enough bags of larvae for 13 villages.

Table 5 presents the enterprise budget for a business selling 195 *H. hebetor* bags to 13 villages. The budget assumes that *H. hebetor* bags are priced at $3.34 per bag which represents the common price used by pilot businesses in the summer of 2015. Table 7 will later show how profits change as the price of bags varies. In reality, INRAN and ICRISAT plan to provide businesses with some basic start-up equipment, which means that total costs are overestimated in this analysis. Also note that the cost of distributing *H. hebetor* bags is borne by villages because village representatives are expected to travel to business locations to retrieve products.

Table 5: *H. Hebetor* Enterprise Budget

Item	Value per 13 villages or 195 bags in US$
Income:	
13 villages x 15 bags at $3.34 per bag ....…………..............................	$651.14
Variable Costs:	
Labor ...……………………………………………………………....	$65.11
Equipment ...………………………………………………………...	$29.32
H. Hebetor bags (includes jute bag and millet mixture) ...…………….	$55.35
Miscellaneous (10% of other variable costs) …………………………	$14.98
Total variable costs ………………………………………..	$164.76
Income above variable costs …………………………….....	$486.38
Fixed Costs:	
Room …………………………………………………………..	$400.70
Equipment ……………………………………………………..	$26.38
Marketing ……………………………………………………...	$8.35
Total fixed costs ……………………………………………	$435.43
Total costs …………………………………………………	$600.19
Estimated profit …………………………………………....	$50.95

*Dollar figures are converted from West African CFA (XOF), so some in-table calculations may be slightly inexact.

The budget estimates that the business will yield a profit of $50.95 in the first year. A few simple manipulations of the budget reveal information on the costs and profits associated with businesses scaled by a factor of 13 villages. Consider the scenario of a business that doubles its sales to 26 villages (or 390 bags). The income and variable costs will be doubled from the original enterprise budget, and the fixed costs will stay the same. Total costs increase by $164.76. Profits increase by $486.38. In summary, an additional 13 villages in sales will increase total costs by $164.76 and profits by $486.38, and these incremental gains can be applied to subsequent factors of 13 villages (39, 52, 65, etc.). Table 6 summarizes the first-year costs and profits at different numbers of sales, holding price constant at $3.34 per bag.

Table 6: Costs and Profits by Sale Volume

# of Village Sales	Revenue	Total Variable Costs	Total Fixed Costs	Total Costs	Profit
13	$651.14	$164.76	$435.43	$600.19	$50.95
26	$1302.28	$329.52	$435.43	$764.95	$537.33
39	$1953.42	$494.28	$435.43	$929.71	$1023.71
52	$2604.56	$659.04	$435.43	$1094.47	$1510.09
65	$3255.70	$823.80	$435.43	$1259.23	$1996.47

Enterprise budgets can be used to conduct a break-even analysis for prices and outputs. The break-even output is the output necessary to just cover all costs at a given output price. The formula for calculating break-even output is:

Break-even output = total costs ÷ output price

We consider output price to be the price for a single village set of bags. Based on the *H. hebetor* enterprise budget, the break-even output based on the costs associated with selling to 13 villages is $600.19 ÷ $50.10 = 11.98 village sales, or 179.70 bag sales. In other words, a village that sells sets of 15 bags for $50.10 must sell a full set to approximately 12 villages in order to cover costs. This calculation assumes that costs are a linear function of output, which is not true because some inputs are fixed. Still, the 12-village figure gives business planners a general sense of the production level needed to break-even when facing costs of $600.19. Table 7 summarizes the break-even outputs for the levels of total cost associated with the number of village sales analyzed in Table 6. The difference between expected output and break-even output highlights that an output of 13 village sales is very close to the minimum output required for a business to break even. The total costs associated with higher levels of output provide a greater cushion between expected output and break-even output.

Table 7: Break-Even Output by Total Cost

Expected Output (# of Village Sales)	Total Costs	Output Price	Break-Even Output (# of villages)	Difference between Output and Break-Even Output
13	$600.19	$50.10	11.98	1.02
26	$764.95	$50.10	15.27	10.73
39	$929.71	$50.10	18.56	20.44
52	$1094.47	$50.10	21.85	30.15
65	$1259.23	$50.10	25.13	39.87

The break-even price is the price necessary to cover all costs at a given output level. It is calculated with the following equation:

Break-even price = total costs ÷ expected output

The break-even price for *H. hebetor* bags based on the costs associated with selling to 13 villages (each purchasing 15 bags) would be $600.19 ÷ 13 villages = $46.17 per village, or $3.08 per bag. Table 8 summarizes the break-even prices for the levels of total cost associated with expected outputs.

Table 8: Break-Even Prices by Expected Output and Total Costs

Expected Output	Total Costs	Break-Even Price per Village	Break-Even Price per bag
13	$600.19	$46.17	$3.08
26	$764.95	$29.42	$1.96
39	$929.71	$23.84	$1.59
52	$1094.47	$21.05	$1.40
65	$1259.23	$19.37	$1.29

In the summer of 2015, all 7 pilot businesses sold individual bags for $3.34 which equates to $50.10 per village that purchased a full set of 15 bags. Although this price already exists in the market, it will be useful for businesses to have a better understanding of their pricing options in the event that they must update prices to stay competitive as the market develops. If they choose a price that is too high, they risk being undercut by competitors. If they choose a price that is too low, they risk not covering their costs. Table 9 presents one-year expected profits based on varying combinations of market size and bag price.

Table 9: Expected First Year Profit from Combinations of Sale Volume and Bag Price

		Sale Volume (# of village buyers)				
		13	26	39	52	65
Price/Bag	$0.42	*-$456.12*	*-$476.81*	*-$497.51*	*-$518.20*	*-$538.89*
	$0.83	*-$383.68*	*-$331.93*	*-$280.19*	*-$228.44*	*-$176.69*
	$1.25	*-$311.24*	*-$187.06*	*-$62.87*	*$61.32*	*$185.50*
	$1.67	*-$238.80*	*-$42.17*	*$154.45*	*$351.07*	*$547.70*
	$2.09	*-$166.36*	*$102.70*	*$371.77*	*$640.83*	*$909.90*
	$2.50	*-$93.92*	*$247.58*	*$589.08*	*$930.59*	*$1272.09*
	$2.92	*-$21.49*	*$392.46*	*$806.40*	*$1220.35*	*$1634.29*
	$3.34	*$50.95*	*$537.34*	*$1023.72*	*$1510.10*	*$1996.49*
	$3.76	*$123.39*	*$682.22*	*$1241.04*	*$1799.86*	*$2358.68*
	$4.17	*$195.83*	*$827.09*	*$1458.36*	*$2089.62*	*$2720.88*
	$4.59	*$268.27*	*$971.97*	*$1675.67*	*$2379.37*	*$3083.07*
	$5.01	*$340.71*	*$1116.85*	*$1892.99*	*$2669.13*	*$3445.27*

Table 9 shows that smaller businesses risk losses if they charge a price much less than $3.34, as was also shown in the break-even price equation. The current market price of $3.34 appears to be a reasonable price from a business perspective in order for smaller businesses to be profitable, and larger businesses can remain profitable at prices as low as $1.25.

V.3. Affordability

Businesses need to keep prices low enough so that a high proportion of farmers within a given village are willing to contribute to a cooperative purchase. The profitability and sustainability of beneficial parasitoid businesses is contingent upon the willingness of enough millet farmers to participate in cooperative purchasing arrangements such that free-riding is discouraged. It is difficult to discern the level of farmer participation required to maintain stability of any given cooperative arrangement, but it is logical that greater farmer participation increases the probability that villages remain committed to purchasing agreements. A higher prevalence of free-riding is more likely to cause village turmoil that could lead to the disintegration of cooperative arrangements. This portion of the study examines a menu of pricing options for the *H. hebetor* bags with special consideration given to the tension between market inclusion and profits. Market inclusion refers to the proportion of any given village that are willing to contribute to a cooperative purchasing agreement at indicated prices.

Survey data on willingness-to-pay for parasitoids provides the most useful available information about farmers' likelihood of free-riding. Farmers who express a lower willingness-to-pay are more likely to be priced out of the market. The survey question concerning willingness-to-pay asks farmers how much they would individually pay for beneficial insects if the insects would eliminate their millet yield losses from the millet head miner. The question indicates nothing about the public good nature of the *H. hebetor* or that villages would be best served to purchase the bags cooperatively, so in theory, the question should elicit responses that closely resemble the value of the parasitoid to each individual farmer. A comparison of farmers' willingness-to-pay versus a menu of potential prices for different-sized villages will illuminate which pricing options are likely to be collectively embraced.

All 398 farmers indicated a positive willingness-to-pay for *H. hebetor*. Values ranged from $0.09 to $25.04. The mean and median values were $4.35 and $1.67 respectively. The mode value was $1.67, representing 21.6% of the sample. A key statistic from the survey is the minimum willingness-to-pay, as this value represents the farmers least likely to enter the market. Based on the survey, the minimum willingness-to-pay is $0.09. If individual farmers face a price of $0.09, a village must contain at least 557 households in order to meet a total village price of $50.10. The average number of households per village in Niger is approximately 240 (Mariko et *al*., 2012; Euromonitor, 2014), well below 557.

To include all farmers, less populous villages would need to pay a higher per-household price or face a lower cost than $3.34 per bag. For example, members of a 240 household village would need to pay $0.21 each in order to meet a village price of $50.10. Alternatively, the 240 households could each pay $0.09 if a single bag costed $1.44. A third option, which will not be considered in this analysis, is for villages to purchase less than 15 bags, the number recommended by entomologists. This option comes with greater risk and uncertainty because entomologists do not know how the effectiveness of *H. hebetor* changes with varying numbers of bags.

Table 10 shows feasible combinations of bag prices and per household contribution associated with different numbers of village households. The column titled "Percent of Farmer Inclusion" refers to the percent of farmers who indicated that they would be willing-to-pay the specified price on the 2015 household survey. This table provides perspective on pricing options available to businesses. Businesses can use this willingness-to-pay chart along with profit forecasts to inform their pricing strategy. Larger villages should have no trouble including all farmers at the current price of $3.34 bag. If bags sell for $3.34 each, villages with over 557 households can afford to pay a price of $0.09 or lower per household. If the per-household contribution rises to $0.17, villages with at least 295 households can afford a bag price of $3.34.

At this price, smaller villages may not be able to attain full inclusion, but they may not need every villager to participate in order to execute and sustain a cooperative purchasing agreement. Based on survey data, villages with between 50 and 250 households could still expect 76-96% participation if faced with a price of $3.34 per bag. The participation rate appears even more promising (91-96%) when villages with over 50 households are considered.

Table 10: Feasible Combinations of Bag Price and Per-Household Contribution based on Village Size (Assuming Villages Purchase Bags Cooperatively)

Household Count	Price per household	Percent of Farmer Inclusion	Single Bag Price	Household Count	Price per household	Percent of Farmer Inclusion	Single Bag Price
50	$0.04	100%	$0.14	**100**	$0.04	100%	$0.28
	$0.09	100%	$0.28		$0.09	100%	$0.56
	$0.13	99%	$0.42		$0.13	99%	$0.83
	$0.17	98%	$0.56		$0.17	98%	$1.11
	$0.21	96%	$0.70		$0.21	96%	$1.39
	$0.33	95%	$1.11		$0.33	95%	$2.23
	$0.50	91%	$1.67		$0.50	91%	$3.34
	$0.67	91%	$2.23		$0.67	91%	$4.45
	$0.83	90%	$2.78		$0.83	90%	$5.56
	$1.00	76%	$3.34		$1.00	76%	$6.67
150	$0.04	100%	$0.42	**200**	$0.04	100%	$0.56
	$0.09	100%	$0.83		$0.09	100%	$1.11
	$0.13	99%	$1.25		$0.13	99%	$1.67
	$0.17	98%	$1.67		$0.17	98%	$2.23
	$0.21	96%	$2.09		$0.21	96%	$2.78
	$0.33	95%	$3.34		$0.33	95%	$4.45
	$0.50	91%	$5.01		$0.50	91%	$6.68
	$0.67	91%	$6.68		$0.67	91%	$8.90
	$0.83	90%	$8.35		$0.83	90%	$11.13
	$1.00	76%	$10.02		$1.00	76%	$13.36
250	$0.04	100%	$0.70	**300**	$0.04	100%	$0.83
	$0.09	100%	$1.39		$0.09	100%	$1.67
	$0.13	99%	$2.09		$0.13	99%	$2.50
	$0.17	98%	$2.78		$0.17	98%	$3.34
	$0.21	96%	$3.48		$0.21	96%	$4.17
	$0.33	95%	$5.56		$0.33	95%	$6.68
	$0.50	91%	$8.35		$0.50	91%	$10.02

	$0.67	91%	$11.13		$0.67	91%	$13.36
	$0.83	90%	$13.91		$0.83	90%	$16.70
	$1.00	76%	$16.70		$1.00	76%	$20.04
400	$0.04	100%	$1.11	**500**	$0.04	100%	$1.39
	$0.09	100%	$2.23		$0.09	100%	$2.78
	$0.13	99%	$3.34		$0.13	99%	$4.17
	$0.17	98%	$4.45		$0.17	98%	$5.56
	$0.21	96%	$5.56		$0.21	96%	$6.96
	$0.33	95%	$8.90		$0.33	95%	$11.13
	$0.50	91%	$13.36		$0.50	91%	$16.70
	$0.67	91%	$17.81		$0.67	91%	$22.26
	$0.83	90%	$22.26		$0.83	90%	$27.83
	$1.00	76%	$26.71		$1.00	76%	$33.39
600	$0.04	100%	$1.67	**1000**	$0.04	100%	$2.78
	$0.09	100%	$3.34		$0.09	100%	$5.56
	$0.13	99%	$5.01		$0.13	99%	$8.35
	$0.17	98%	$6.68		$0.17	98%	$11.13
	$0.21	96%	$8.35		$0.21	96%	$13.91
	$0.33	95%	$13.36		$0.33	95%	$22.26
	$0.50	91%	$20.04		$0.50	91%	$33.39
	$0.67	91%	$26.71		$0.67	91%	$44.52
	$0.83	90%	$33.39		$0.83	90%	$55.65
	$1.00	76%	$40.07		$1.00	76%	$66.78

Note that Table 10 displays information on a maximum of 1,000 households. This is a rough estimation of the number of households within the area feasibly reached by *H. hebetor*. *H. hebetor* in open fields can control pests within a 5 km radius which equates to an area of 7854 hectares. The farmer survey from 2015 indicated that the mean area of cultivated land was 5.8 hectares. Based on this median farm size, *H. hebetor* will be able to reach about 1354 households assuming that all hectares are used for farming. Of course, village land is also used for dwellings, and some land does not support agriculture. Also, there may be multiple small villages within the confines of a 7854 hectare area, or there may be large villages that exceed the confines of 7854 hectares. Small nearby villages will be best served to share the purchase of one set of *H. hebetor*, and large villages may need to buy more than 15 bags and stagger them across multiple circles of 5 km radius. Table 10 should be viewed as a menu of hypothetical per-household contribution scenarios regardless of the exact number of households that are feasibly within a given area.

We must mention that our hypothetical scenarios depend upon farmers' ability to organize cooperative purchases. We know that farmer groupements have experience pooling money together to purchase inputs, but most farmers do not belong to these groups. In our 2015 household survey only 15% of farmers indicated that they belong to a groupement. This statistic begs the question of whether it is truly feasible for a village to collect small amounts of money (like $0.09) from many hundreds of households. Though this seems like a daunting task, a potentially simple solution is for village leaders to add the small charge to village taxes or dues. An across-the-board fee is a payment mechanism that can help to ensure that free-riding is impossible.

V.4. Worker Benefits

In order for the biological control industry to attract rearing technicians, businesses must provide opportunities for workers to earn more than their next best employment opportunities. Based on the precedent of pilot businesses in 2015, businesses are expected to have three workers, and these workers are expected to be paid 10% of total revenue. Workers decide how to split this value amongst themselves. Future businesses are not beholden to these practices, but we will use these assumptions for our analysis. Because income is calculated based on a revenue percentage, daily wages depend on volume and price of sales. It is simple to calculate total individual wages based on varying sale prices and volumes, but it is difficult to translate this value into a daily or hourly wage because we do not have precise estimates of the number of hours required to perform different tasks for varying levels of demand. In order to estimate the daily wage of workers, we must make assumptions about the timeline required to operate a business and the amount of labor required in different periods of business operation. Because it is difficult to quantify how labor hours changes with demand, we will use advice from INRAN to make simplistic, conservative assumptions regarding this relationship.

We will assume that businesses require labor from late-May through late-August for a total of three months or approximately 90 days. In the first month, from late-May to late-June, the sole business task is for one worker to rear *C. cephalonica*, which requires only one day of work to set up rearing buckets, regardless of *H. hebetor* demand. Once rearing buckets are set up in late-May, the next month is work-free other than the occasional check-up on the *C. cephalonica* multiplication process. We will consider this month long period to account for two full (8 hour) work days, one for set-up and one for planning.

In the second month (late-June to late-July), workers must mass-multiply *H. hebetor*. Transferring *H. hebetor* between petri dishes and mating cages is not a particularly labor intensive activity, able to be completed by one person over 2.5-20 hours per week depending on demand and the time of the month. The work will become more time consuming over the course of the month as the number *H. hebetor* increases. As demand increases, daily hours will increase but not substantially. Table 11 defines assumptions about required labor hours for businesses with varying levels of demand based on multiples of 13 village buyers.

We will consider the third month to be the time for preparing and selling bags, and this will be the most labor intensive month by far. Based on the recommendation of INRAN's rearing technician, we will assume that two workers can prepare approximately 200 bags in one full eight hour work day. Additionally, we will assume that the sales process requires one worker to be present at a store for four hours per day for the entire month. This worker will make transactions and explain the technique for releasing bags to customers. A final assumption states that one other worker will be available for 2 hours of daily labor, regardless of demand, to maintain *H. hebetor* stocks and provide miscellaneous tasks such as marketing. Table 12 defines assumptions about required labor hours for the third month of operations at varying levels of demand, and Table 13 summarizes the total number of labor hours and full workdays (8 hr) required for all three months.

Table 11: Estimated daily labor hours required for multiplying *H. hebetor* over the course of one month, based on varying market demand

Market Demand (# of village buyers)					
	13	26	39	52	65
Labor Hours in 1st week	*2.5*	*5.0*	*7.5*	*10.0*	*12.5*
Labor Hours in 2nd week	*7.5*	*10.0*	*12.5*	*15.0*	*17.5*
Labor Hours in 3rd week	*12.5*	*15.0*	*17.5*	*20.0*	*22.5*
Labor Hours in 4th week	*17.5*	*20.0*	*22.5*	*25.0*	*27.5*
Total Monthly Labor Hours	*40*	*50*	*60*	*70*	*80*

Table 12: Daily labor hours required during third month of operation, based on varying market demand

Market Demand (# of village buyers)					
	13	26	39	52	65
Total Labor Hours (assuming a 5-day work week)	*136*	*152*	*168*	*184*	*200*

Table 13: Labor hours by month, total labor hours, and number of full workdays required for one season of business based on varying market demand

Market Demand (# of village buyers)					
	13	26	39	52	65
Labor hours in Month 1	*16*	*16*	*16*	*16*	*16*
Labor hours in Month 2	*40*	*50*	*60*	*70*	*80*
Labor hours in Month 3	*136*	*152*	*168*	*184*	*200*
Total Labor Hours	*192*	*218*	*244*	*270*	*296*
Number of full workdays (8 hr) corresponding to total labor hours	*24*	*27.25*	*30.5*	*33.75*	*37*

In total, business operations are assumed to require between 192-296 hours of work, or 24-37 full work days (8 hours/day) split between three workers over three months. Table 14 reports estimates of daily wages based on varying levels of sale volumes and prices. Note that these estimates assume that workers are paid a total of 10% of sales revenue and this value is split evenly among three workers.

How do the daily wages presented in Table 14 compare to the daily wages of workers' next best employment opportunities? According to INRAN and ICRISAT, workers are expected to be members of farmer unions who have some level of formal schooling, and they are likely unemployed or employed in unskilled agricultural work. The minimum wage in Niger as of 2012 is $50.17/month or approximately $1.67/day, but many people in Niger earn below this level (Tijdens et *al*., 2012). In 2012, skilled agricultural workers earned $0.14/hour or $1.12 per eight hours (Tijdens et *al*., 2012).

Table 14: Daily Wage based on Combinations of Market Sizes and Bag Prices (Italicized Values Represent Individual Daily Wages)

		Market Size (# of village buyers)				
		13	26	39	52	65
Price/bag	$1.67	*$0.45*	*$0.80*	*$1.06*	*$1.29*	*$1.47*
	$2.09	*$0.57*	*$1.00*	*$1.33*	*$1.61*	*$1.83*
	$2.50	*$0.68*	*$1.19*	*$1.60*	*$1.93*	*$2.20*
	$2.92	*$0.79*	*$1.39*	*$1.87*	*$2.25*	*$2.57*
	$3.34	*$0.90*	*$1.59*	*$2.13*	*$2.57*	*$2.93*
	$3.77	*$1.02*	*$1.79*	*$2.40*	*$2.89*	*$3.30*
	$4.17	*$1.13*	*$1.99*	*$2.67*	*$3.22*	*$3.67*
	$4.59	*$1.24*	*$2.19*	*$2.94*	*$3.54*	*$4.03*
	$5.01	*$1.36*	*$2.39*	*$3.20*	*$3.86*	*$4.40*

Table 14 highlights the combinations of sale price and quantity that result in wages greater than $1.67/day and/or $1.12/day, in red and blue respectively. This table shows that many combinations of price and quantity yield wages above what unskilled agricultural workers earn. At the prevailing market price of $3.34/bag, all market sizes intervals cover a $1.12/day wage with the exception of the 13-village market. Paying workers a higher wage than 10% of bag revenue would be a relatively simple way for businesses to meet fair wage standards if they do not already do so. The major takeaways from Table 14 are that fair and competitive wages are achievable for businesses, and that changes to price and wage percentages can accommodate markets of different sizes.

V.5. Farmer Benefits

Pricing of *H. hebetor* must be carefully considered in order to ensure that farmers are indeed economically benefitting from purchases. If a farmer is willing to purchase *H. hebetor*, it is assumed that the purchase is beneficial, but the true value of the insect to the farmer may differ from the farmer's perceived value. Millet farmers are aware of insect pests and their associated damage to millet, but damage from insects is difficult to quantify (Youm and Owusu, 1998).

Farmers are expected to receive substantial net benefits from purchasing *H. hebetor*, but it will still be useful for researchers to establish a benchmark estimate of the value of *H. hebetor* to compare with farmers' stated willingness-to-pay and proposed product prices in order to ensure that farmers can benefit from a variety of purchasing arrangements.

The estimated value of beneficial insects is calculated based on *H. hebetor*-induced yield increase rates, household millet production statistics, and market millet prices. In a study of the relationship between *H. hebetor*, millet head miner damage, and grain yields, Baoua et *al*. (2014) found that augmentative releases of *H. hebetor* reduced grain losses from infested plants between 8% and 41%, with an average loss reduction of 34%. It is important to distinguish that these figures represent loss reductions from only infested plants and that not all plants will necessarily be infested. The same study found that the millet head miner infested 2% - 88% of millet plants in fields, with an average infestation of 64%. Presumably, the villages that purchase parasitoids have high risk of large infestations, so we will only examine moderate to high infestation levels. For the purpose of this study, we will assume that villages who would be interested in purchasing *H. hebetor* have between 25% - 100% infestation. Combining these infestation rates with the aforementioned grain loss reduction rates, we calculate a wide range of potential *H. hebetor*-induced yield increase rates per field, 2% - 41%. Using the average figures from Baoua et *al*. (2014), we find an average *H. hebetor*-induced yield increase rate per field of 21.76%.

The 2015 farmer survey indicated that the median quantity of millet produced was 900 kg per household, and the most recent millet price data suggests that average annual millet price from 2009 to 2012 was $0.33 per kilogram (FAO, 2014). A farm that yields 900 kg of millet can expect to gain 18 kg – 369 kg from *H. hebetor* control which equates to $5.94 - $121.77 in recovered value. This range of values is significantly higher than any proposed per-household price of *H. hebetor*. The current market price for a set of 15 insect bags is $50.10 which covers an entire village. Table 15 presents the value of improved yields for farms with varying levels of millet production. Assuming that farmers will face prices within the range of the per-household prices from Table 10, farmers are unambiguously expected to have net benefits even at low levels of production and low yield increases. Higher levels of parasitoid effectiveness can be extraordinarily valuable.

Table 15: Value of Reduced Grain Loss, based on Varying Levels of Millet Production and Pest Control Effectiveness

Annual Household Millet Production (percentiles based on 2015 farmer survey)	Parasitoid-Induced Grain Loss Reduction (2-41%)	Value of Yield Increase
312.5 kg (10th percentile)	6.3 – 128.1 kg	$2.08 - $42.27
500 kg (25th percentile)	10.0 – 205.0 kg	$3.30 - $67.65
900 kg (50th percentile)	18.0 – 369.0 kg	$5.94 - $121.77
1625 kg (75th percentile)	32.5 – 666.3 kg	$10.73 - $219.88
3400 kg (90th percentile)	68 – 1394 kg	$22.44 - $460.02

V.6. Risk

In reality, businesses are fraught with risks that are not accounted for in our deterministic budgets analyses. Potential risks include failure in rearing parasitoids, varying input costs, inconsistent demand, failure of timely bag pick-up by villages, and failure of initial *H. hebetor* stock by research institutions. These risks are briefly examined in succession.

V.6.a. Failure in Rearing or Maintaining Parasitoids

From a business perspective, a failure in rearing or maintaining parasitoids would be disastrous, but precautions can be taken to hedge against this risk. Due to human error and/or natural causes, parasitoids could escape, demise, fail to reproduce, or be reared too late to prevent millet head miner damage. A system could be developed where businesses agree to maintain extra *H. hebetor*, spread amongst multiple locations. This solution was put on display during the 2015 season. A pilot business in Dantiandou failed to rear parasitoids in a timely manner, and a business from Maradi was able to ship parasitoids 500 km to meet Dantiandou's demand. By the nature of the rearing process and the uncertainty of demand in a given year, businesses should be multiplying vast numbers of *H. hebetor* that exceed the number that they will sell. Once mass multiplication begins, maintaining large amounts of parasitoids will not require substantially more work or equipment. Tending toward an earlier rearing start date is a safe way to rear extra parasitoids and ensure that sufficient levels of parasitoids are ready to be placed in fields in a timely manner. It is important for businesses to maintain a communication network with other businesses in order to implement a risk management strategy.

V.6.b. Varying Input Costs

Rearing rooms and labor account for an estimated 58%-78% of total costs based on the varying levels of demand analyzed in Table 6, and neither of these inputs' prices are expected to vary significantly. Other inputs are relatively basic and cheap materials that are not expected to see large price variation. Input costs are more likely to currently be greatly overestimated because it is possible that some businesses will receive rearing rooms for free. A business associated with a farmer union may receive free rooms controlled by the farmer union, resulting in increased profits of between 20% and 786% depending on the level of demand. Budgets from section V.2 can be considered scenarios that account for high cost risk.

V.6.c. Inconsistent Demand

Because historic data on the location of millet head miner infestations is not available, there is no way to predict year-to-year sale fluctuations in sales. However, new businesses, with consultation from research institutions, should develop in regions that usually have a millet head miner problem. Additionally, businesses should serve a wide enough geographic area to provide adequate opportunities for sales. Serving a wide area is insurance against sporadic local demand. This issue is discussed at greater length in section V.4. Although the budget projections in section V.2 only account for one year, the menu of scenarios based on varying levels of sales provides businesses with some information about the impact of fluctuating demand.

V.6.d. Failure of Timely Bag Pick-Up

The inability of buyers to travel to business locations to retrieve *H. hebetor* in a timely manner is a potential risk for businesses. If farmers release *H. hebetor* too late in the season to control the millet head miner, they may believe that the technology is ineffective, so it is in businesses' best interest to ensure timely delivery. Businesses can account for this risk by being willing to deliver *H. hebetor* in certain instances. We can estimate the delivery cost for businesses using the cost of motorcycle fuel and driver wages. Motorcycles are the best means of transportation because they can access off-road paths that are inaccessible to buses and cars. *H. hebetor* bags are small enough to fit in a backpack or box attached to the motorcycle, and bags will not be disturbed by one day of travel.

We do not know the number, distance, or timing of deliveries, but we will make some assumptions based on guidance from INRAN. Businesses are unlikely to travel further than 150 km, and a reasonable average travel distance is 75 km. Presumably, multiple deliveries could be completed in a single trip, but there is no way to know how trips could unfold geographically. We will assume that businesses will have the capacity to take 5 annual emergency delivery trips covering 75 km and perhaps spanning multiple villages in a single trip. Workers are likely to have access to a personal motorcycle or a motorcycle belonging to a farmer union. Fuel costs

$0.83/liter, and one liter can provide 30 km of travel. A driver could be paid $1.67/trip. One average delivery of 75 km would cost $3.75, and five trips would cost $18.75. This cost represents 1% - 3% of total costs and 1% - 37% of profits, based on budget calculations presented earlier in Table 6. The 37% figure characterizes a business that sells to 13 villages which is close to the break-even output. This percentage quickly drops to 3% if businesses double their sales to 26. Despite a lack of precise data related to transportation costs, these estimated figures suggest that businesses should have a sufficient cash flow to cover the transportation costs of emergency deliveries.

V.6.e. Failure of Initial Parasitoid Delivery

Businesses must receive initial mated parasitoid females in late June or early July from INRAN or ICRISAT. This is a critical delivery, because if the initial parasitoids do not arrive, businesses cannot begin the mass multiplication process. To address this risk, one business or a few businesses could potentially maintain a low stock of *H. hebetor* throughout the year. Year-round operation would be simple and inexpensive. A business could perform the necessary tasks using its existing equipment, and labor would only involve the occasional transfer of parasitoids between petri dishes and mating cage, requiring an estimated one hour per week. Tasks are simple and quick but cannot be neglected if parasitoids are to survive the duration of the 9 month "off-season." A business must be incentivized to ensure the year-round sustainment of the parasitoid population. Assuming that the nine month "off-season" requires 39 hours of total work and a worker earns the average hourly wage of a skilled agricultural worker ($0.14), total labor cost is approximately only $5.47 for the entire nine-month period. Presumably, businesses would face some other minor costs over time, and they could potentially demand additional compensation for undertaking a great responsibility. However, a single year-round rearing business seems economically feasible if the cost of year-round maintenance is split between all other *H. hebetor* businesses. This additional business activity appears promising as a precautionary measure, although it is unlikely that INRAN or ICRISAT would fail to fulfill their delivery obligations or discontinue their stock of a parasitoid that is actively the subject of continued experimentation.

V.7. Market Potential

Total market potential, i.e. the maximum number of potentially profitable businesses, is an important consideration for all actors involved in the prospective *H. hebetor* market including farmers, researchers, and prospective business owners. The market consists of poor subsistence farmers living in scattered, sometimes isolated rural areas, who may have difficultly accessing *H. hebetor* in the absence of the geographical coordination of businesses. With a vested interest in the livelihoods of these farmers, researchers want to ensure that the technology is widely available to farmers who are susceptible to the millet head miner. This begs the question of how many businesses are needed to satisfy widespread demand. The potential number of viable businesses is also a significant piece of information for entrepreneurs considering market entry. In reality, the number of businesses will evolve with unpredictable market forces, but research organizations have the ability to influence business origination due to their established relationships with farmer organizations and their necessary role in providing *H. hebetor* businesses with equipment and expertise.

This section begins with an examination of factors that are relevant to the question of where to locate businesses, and these factors are then used to infer how many businesses are needed to satisfy widespread demand for those susceptible to the millet head miner. The purpose of this exercise is not to strictly quantify market size but rather to collect information relevant to market size in order to make broad statements about the potential number and location of businesses. The following factors are thought to be relevant to business location decisions, and consequently, total market potential: presence of the millet head miner, proximity of location relative to population centers, distinction of being the headquarters of a farmer union, and relationship between local farmer unions and research institutions. These factors are described in succession, followed by recommendations for market organization.

V.7.a. Business Proximity to Millet Head Miner and Millet Production

A clear criterion for choosing a viable *H. hebetor* business location is a close proximity to farms affected by the millet head miner. It is known that the head miner is widespread in each region of the Sahel, but there is no readily available data on head miner activity by village or region. Local knowledge will be paramount in identifying head miner activity. Government extension agents commonly use the following rules of thumb for predicting head miner activity in order to warn villages about oncoming infestations:

(1) Early plantings of millet have a higher risk of infestation than late plantings.

(2) Farmers who had the pest problem last year are more likely to have it this year.

(3) Sandy soils have higher risk than clay soils.

Due to a lack of local data, it is difficult to precisely attribute any of these predictors to geographic areas, but we can conclude that the government extension service will be a valuable source for evaluating potential business locations. In the absence of data on millet head miner presence, millet production serves as a reasonable proxy. The millet head miner is consistently the most problematic insect across the Sahel, and it could be a potential problem for any farm that grows millet. Since millet is grown by farmers all over the region, it is safe to say that the millet head miner is a potential problem for all farms in every part of the Nigerien Sahel. Table

16 provides millet production statistics for each region from 2008-2012. The regions of Dosso, Maradi, Tahoua, Tillaberi, and Zinder all have relatively high average levels of millet production, between 560,000 and 760,000 tons per year.

Table 16: Niger Regional Millet Production (Annuaire Statistique du Niger, 2008 – 2012); Unit 1000 tons

	2008	2009	2010	2011	2012	Avg. from 2008-2012
Agadez	0.0	72.0	0.0	0.2	0.1	14.5
Diffa	67.9	29.9	79.3	47.9	91.3	63.3
Dosso	716.6	627.5	759.2	552.8	686.1	668.4
Maradi	776.3	615.7	867.0	650.2	872.0	756.2
Tahoua	725.9	460.1	729.0	548.1	757.4	644.1
Tillaberi	676.1	488.1	768.3	399.4	751.1	616.6
Zinder	508.3	437.5	620.2	554.7	686.0	561. 3

The remainder of this analysis will only focus upon Dosso, Maradi, and Tillaberi because these regions are home to the farmer federations (Mooriben and FUMA Gaskiya) that are being targeted by INRAN and ICRISAT for initial business locations. It is the hope of INRAN and ICRISAT that businesses will ultimately serve millet farmers throughout the country, but Dosso, Maradi, and Tillaberi were seen as promising regions for a smaller-scale initial launch.

V.7.b. Business Proximity to Population Centers

Since most farmers in the Sahel rely on millet, it will be advantageous for businesses to locate in close proximity to larger populations in order to minimize transaction costs for both businesses and farmers. Table 17 displays department population statistics for Dosso, Maradi, and Tillaberi.

Table 17: Population by Department within the Dosso, Maradi, and Tillaberi Regions (Annuaire Statistique du Niger 2006-2010)

Region Department	Population (2011)	**Region** Department	Population (2011)	**Region** Department	Population (2011)
Dosso		**Maradi**		**Tillaberi**	
Boboye	372,904	Aguie	386,197	Filingue	553,127
Dogondoutchi	682,289	Dakoro	606,862	Kollo	443,371
Dosso	488,509	Guidan Roumji	485,743	Ouallam	383,632
Gaya	349,794	Madarounfa	612,798	Say	316,439
Loga	184,843	Mayahi	546,826	Tera	579,658
		Tessaoua	479,384	Tillaberi	295,898
Total	2,078,339	Total	3,117,810	Total	2,572,125

Table 17 shows that population is spread relatively evenly across the three targeted Sahelian regions and amongst departments. The vast majority of departments have between 300,000 and 600,000 people. Figure 4 provides a visual representation of population density in Niger. In Maradi, population density is greatest around and to the south of the city of Maradi. In Tillaberi, density is concentrated in a strip following the Niger River, and the Dosso region has an equally high concentration across the entire region. These areas of highest concentration are more or less mirrored by the location of farmer union headquarters as shown in in Figures 5 and 6, which is convenient because farmer union headquarter locations are also thought to be advantageous for business locations. Note that maps do not include all headquarter towns due to an inability to access comprehensive maps.

Figure 4: Niger Population Density
(Blanford, Kumar, Luo, MacEachren, 2012)

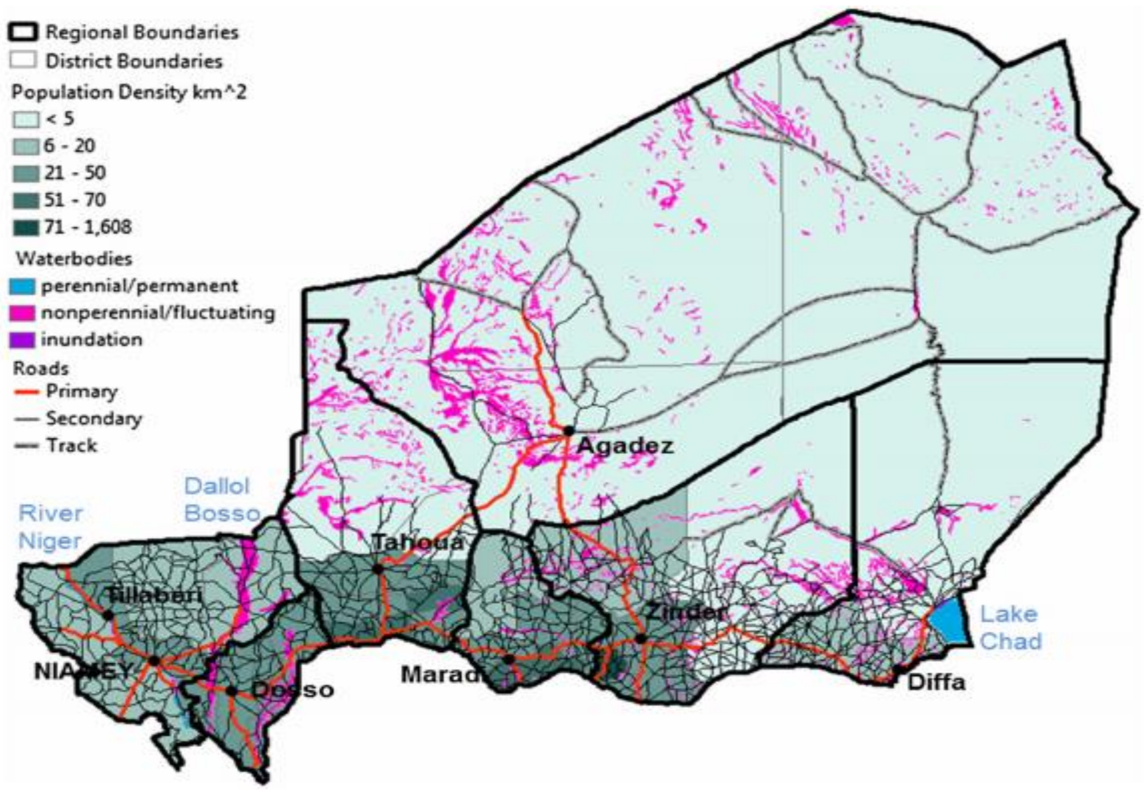


Figure 5: Mooriben Farmer Union Headquarters

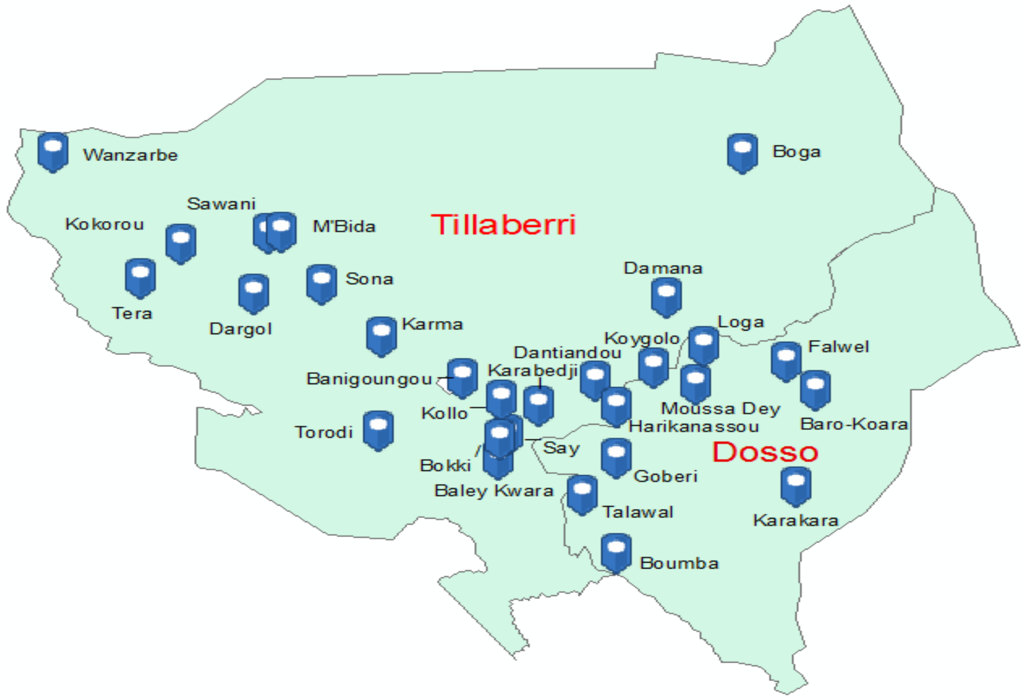
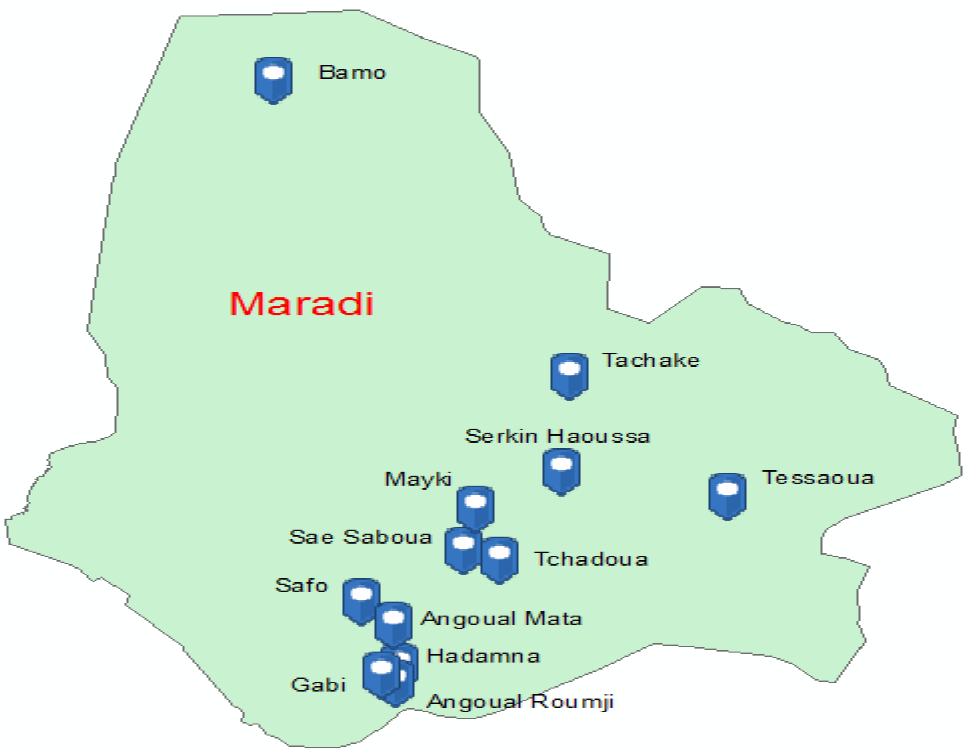


Figure 6: FUMA Gaskiya Farmer Union Headquarters



V.7.c. The Advantage of Locating in Farmer Union Headquarter Towns

Farmers and prospective businesses would both benefit if businesses located in towns that serve as a farmer union headquarters. These towns usually host union inputs shops that sell farm inputs from a storefront at a weekly village market. Using a pre-existing market infrastructure would eliminate transaction costs for some farmers who would regularly attend the weekly market in the absence of the *H. hebetor* product. It would also provide a convenient place for businesses to sell their product. Businesses can use input shops assuming that new businesses will be associated with farmer unions, which is likely given that unions are respected organizations who already sell farm inputs and have relationships with INRAN and ICRISAT. In the private business pilot-test of 2015, five of six businesses were associated with farmer unions. Being associated with a farmer union has the added advantage of utilizing existing communication networks that can assist businesses with marketing products and spreading technical guidance related to biological control.

Tillaberi, Dosso, and Maradi have 18, 12, and 17 unions respectively. Tillaberi and Dosso's unions are members of the Mooriben federation, and Maradi's unions are members of the FUMA Gaskiya federation.

V.7.d. Relationship between Farmer Unions and Research Institutions

The relationship between farmer unions and research institutions is likely to influence business locations for multiple reasons. INRAN and ICRISAT are confident that they can discern between promising business candidates and less hopeful ventures. Unions are heterogeneous with regards to level of activity, motivation, and effectiveness in executing their duties. INRAN and ICRISAT have become familiar with different farmer unions through intermittent projects and outreach efforts. Additionally, research institutions have knowledge of union exposure to *H. hebetor* experiments which is hypothesized to increase adoption of the technology. Targeting these farmers may be a wise decision for businesses trying to establish a consumer base before branching out to consumers less familiar with the technology.

V.7.e. Number of Potential Businesses

Due to erratic spatial demand, there is a limit to the number of businesses that can sustain profitability. Although demand for *H. hebetor* is expected to be geographically widespread, any millet-growing area may or may not be faced with a millet head miner problem in a given year. There may be years when the villages comprising the union do not have a serious millet head miner problem, so it would not make sense for every union to develop its own *H. hebetor* business. A profitable business will require a geographically diversified demand base that extends beyond the boundaries of a union. *H. Hebetor* can be transported across far distances as exemplified by a 2015 pilot business in Maradi that shipped the insects over 500 km to Dantiandou because the business in Dantiandou was not able to rear a sufficient number of insects in a timely manner.

The number of businesses should likely be less than the number of farmer unions in a region. We can crudely estimate village coverage per business by varying the hypothetical number of total businesses and assuming that businesses serve equal numbers of villages. These estimates assume that villages are spread in such a way that one village requires one set of bags. For a scenario in which approximately half of unions set up businesses, Mooriben would have 15 units that each serve about 49 villages, and FUMA Gaskiya would have 9 units that each serve about 18 villages. If approximately one-third of unions set up businesses, Mooriben would have 10 units that each serve about 73 villages, and FUMA Gaskiya would have 6 units that serve about 27 villages. These simple calculations have limited practicality because they do not account for spatial realities, but they do provide some sense of how coverage could be distributed amongst businesses. There is no ideal number of villages per business, but businesses must cover a wide enough area to ensure a minimum number of annual customers. From our earlier break-even output analysis, we estimate that 12 villages sales are needed to cover costs. Businesses will not actually restrict their coverage to a set number of villages, but they will benefit from an improved understanding about the scope of their potential demand pool. As stated earlier, the number of businesses will evolve with unpredictable market forces, but research organizations have the ability to influence business origination.

Chapter VI. – Econometric Results

VI.1. Checking OLS assumptions

To arrive at our preferred OLS model, we examined the data to see how well they meet OLS assumptions. We examined outliers, functional form, linearity, multicollinearity, heteroskedasticity, and omitted variables, which are explained below in succession.

Outliers: Several outliers in the data were removed based on various STATA diagnostic tools and researcher perception of their feasibility. First, we examined the dependent variable representing willingness-to-pay (WTP) for beneficial insects. The major concern regarding this variable was that some farmers might have stated very high levels of WTP that do not realistically portray prices that they would or could pay in a real marketplace. A histogram reveals that this variable has an extreme right-skew with several levels of WTP that are many times greater than the bulk of the distribution (Appendix 1.1). Interestingly, we cannot say that any farmers, even the ones expressing the highest level of WTP ($167.96 CFA), overvalued *H. hebetor* based on the estimated values attributed to the *H. hebetor* in Table 14 of Section V.5 ($1.02 - $470.12). However, researchers from Niger suggest that some of these values are not realistic prices for farmers to pay for a product, and from a visual inspection, some values seem certain to affect regression results. A few of these WTP values stand out as clear outliers, but it is ambiguous whether numerous other values on the high-side of the distribution would skew regression results.

To help identify outliers in WTP, we followed a procedure suggested by the UCLA Statistical Consulting Group, which examines measures of influence. Using two STATA tests that measure the general influence of observations on regression coefficients (Cook's D and DFITS) and comparing these measurements to conventional cut-off points, we identified 10 observations that highly influence regression results and exhibit high levels of WTP (results shown in Appendix 1.2). According to UCLA Statistical Consulting Group, "these measures both combine information on the residual and leverage. Cook's D and DFITS are very similar except that they scale differently but they give us similar answers." In essence, these tests tell us how the regression function changes when a single observation is deleted. In generating measures of influence, these tests account for all variables in the regression, so it is not necessarily the case that the influence of observations can simply be attributed to high levels of WTP. However, in examining the test results, it is clear that WTP is the main variable that drives influence, as the WTP variable is the only variable that could conceivably be considered a problematic outlier for the implicated observations. It appears that influential observations have values of WTP greater than or equal to $33.40. Having large influence on a model does not automatically condemn observations as outliers, but it does warrant greater inspection. Based on the extremely skewed distribution of the dependent variable, the influence tests, and considerations of market feasibility, we chose to remove all observations for which WTP is greater than or equal to $33.40, totaling 16 observations. Observations were removed above and beyond the 10 indicated by influence tests in order to implement a consistent cut-off rule. The 16 observations account for only 3.3% of total observations. They exhibit considerably higher levels of WTP than the bulk of observations and are deemed to be represent unrealistic predictions of marketplace behavior.

There are only three independent variables under consideration for our model that can be checked for outliers given that the other variables are dummy variables which can only take two values. These variables represent age, value of animals, and quantity of millet produced. We chose to drop one observation based on age, two observations based on quantities of millet produced, and two observations based on the weighted value of animals. These observations were removed for a variety of reasons. One of the animal values (*animalswt*=50.25) stood out as a clear outlier, almost twice as high as the second highest value for this variable, and another was believed to be a data entry error. For millet production (*milprod*), two observations were dropped because they were deemed infeasible quantities of millet for a farmer to produce (>10,000 kg). For age, one outlier (age 100) was removed because it appears to affect the linearity between the predictor and response variables and stands out to a degree that would appear to influence the regression. Linearity is explained later in a later subsection.

<u>Functional Form</u>: Prior to examining linearity and heteroscedasticity, we considered our functional form, which has consequences for both linearity and heteroscedasticity. Using a

natural log specification for our dependent variable is appropriate for several reasons. It helps to normalize a positive skewed distribution of residuals, which is important because normality of unobserved error in the population is an assumption required for statistical inference (Wooldridge, 2015). Figure 7 shows a kernel density graph of residuals from our originally proposed regression, using levels of willingness-to-pay as our dependent variable as opposed to a logarithmic specification. The graph is overlaid with a normal distribution. Figure 8 shows a similar graph for the original model with a logarithmic specification of the dependent variable. The logarithmic specification clearly improves the fit of residuals to a normal distribution. A logged dependent variable can also mitigate heteroscedasticity and improve the linear fit between our response variable and predictor variables, which are both necessary to meet the assumptions of linear regression. These issues are discussed in greater detail later in the next two subsections.

Figure 7: Kernel Density Graph of WTP using levels of WTP

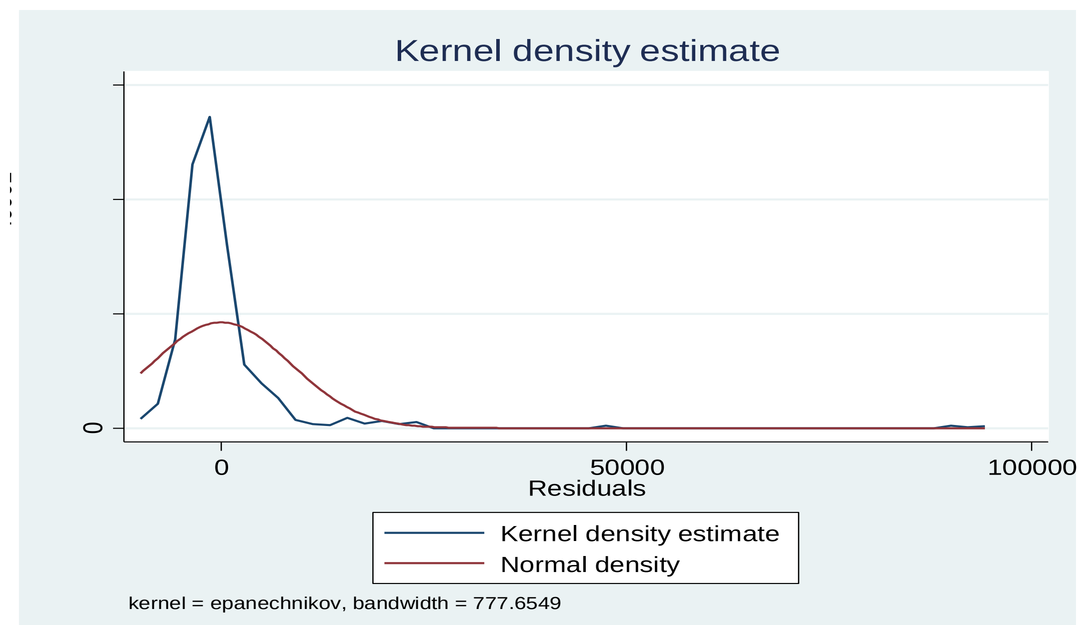
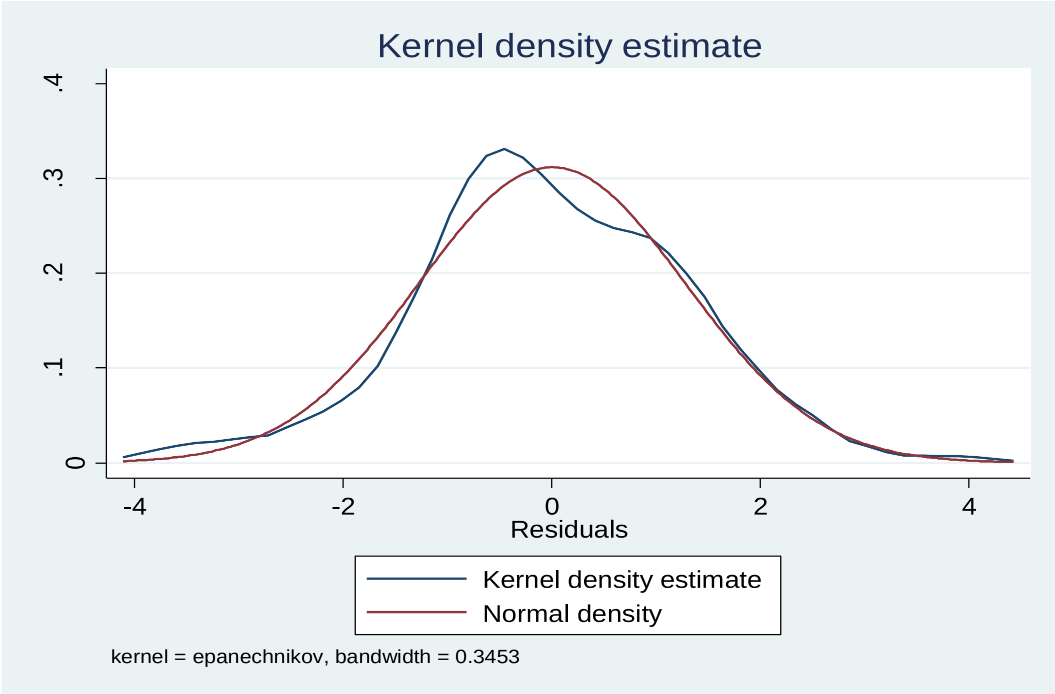


Figure 8: Kernel Density Graph of ln(WTP)



Linearity: Linear regression assumes a linear relationship between the response variable and the predictor variables. We use augmented component-plus-residual plots to identify problems of nonlinearity. These plots are only of use for examining trends in continuous variables, so our discussion is limited to age, quantity of millet produced, and weighted number of animals. Figures 9 and 10 shows the augmented component-plus-residual plot for age before and after dropping a single outlier, respectively. In Figure 9, there is a deviation from linearity for high levels that appears to be driven by one outlying observation (age 100). Dropping this observation, we see that the relationship between our observed data seems to follow a relatively linear trend as exemplified by how the green line (created with our data using locally weighted scatterplot smoothing) more or less follows the blue line (ordinary regression line) in Figure 10. This same procedure is repeated for the variables representing millet production and animal value as shown in Figures 11 and 12. These figures provide a sense that the millet production and animal value variables are fairly close to being linear predictors of the response variable.

Figure 9: Augmented Component-Plus-Residual Plot for *Age*

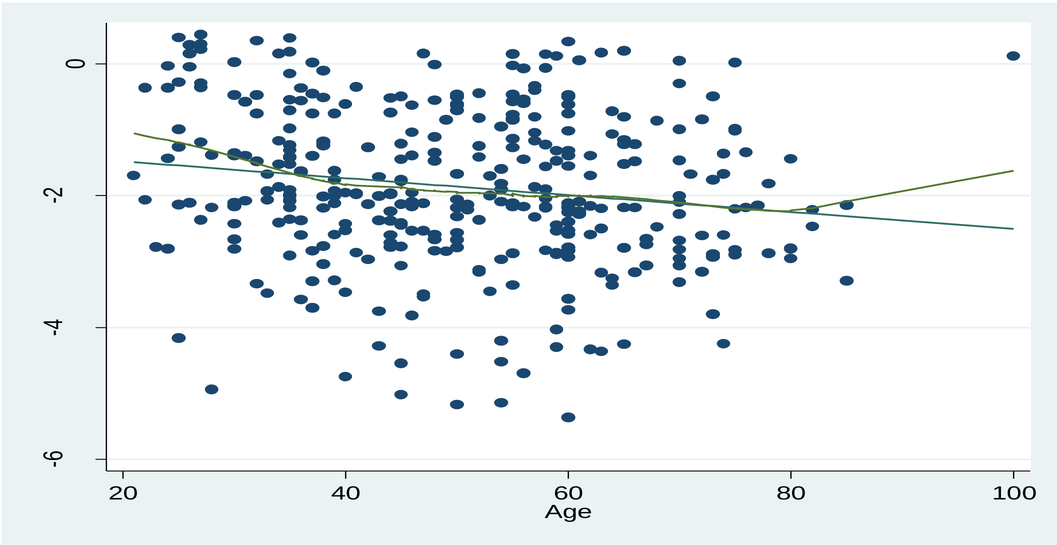


Figure 10: Augmented Component-Plus-Residual Plot for *Age*

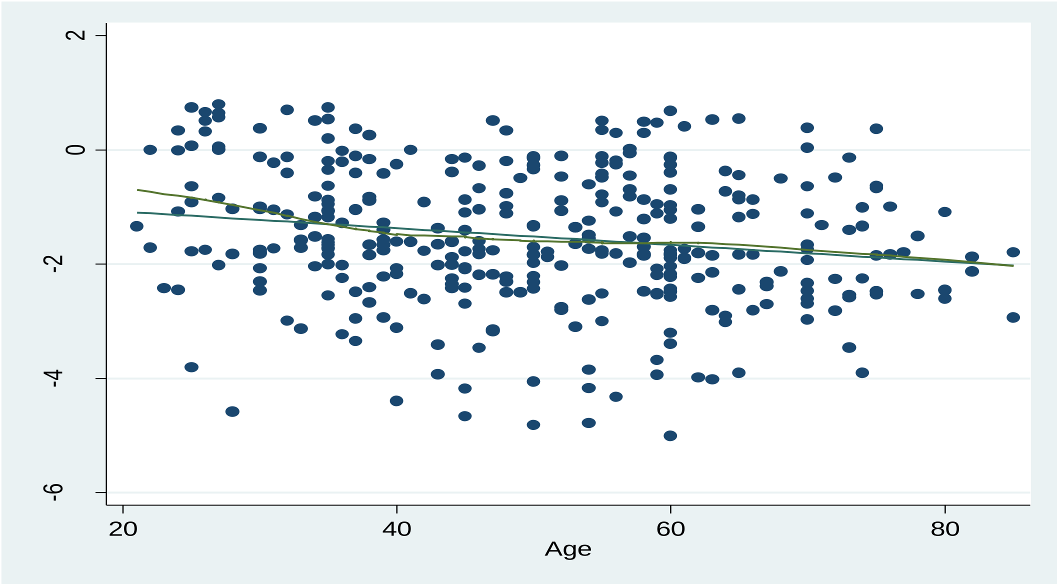


Figure 11: Augmented Component-Plus-Residual Plot for *Milprod*

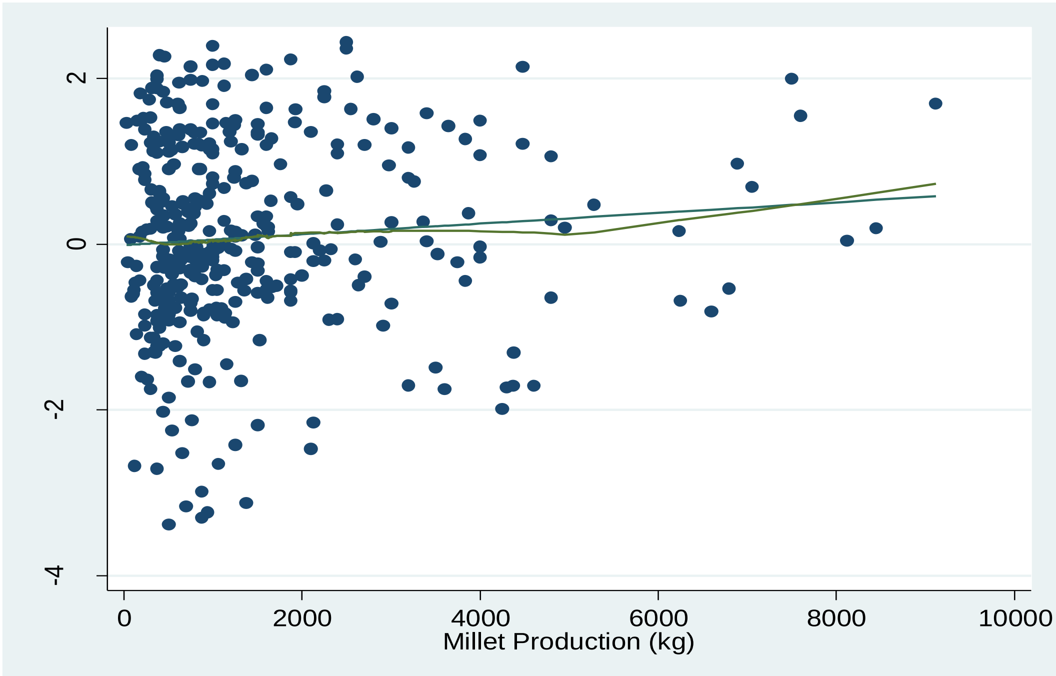
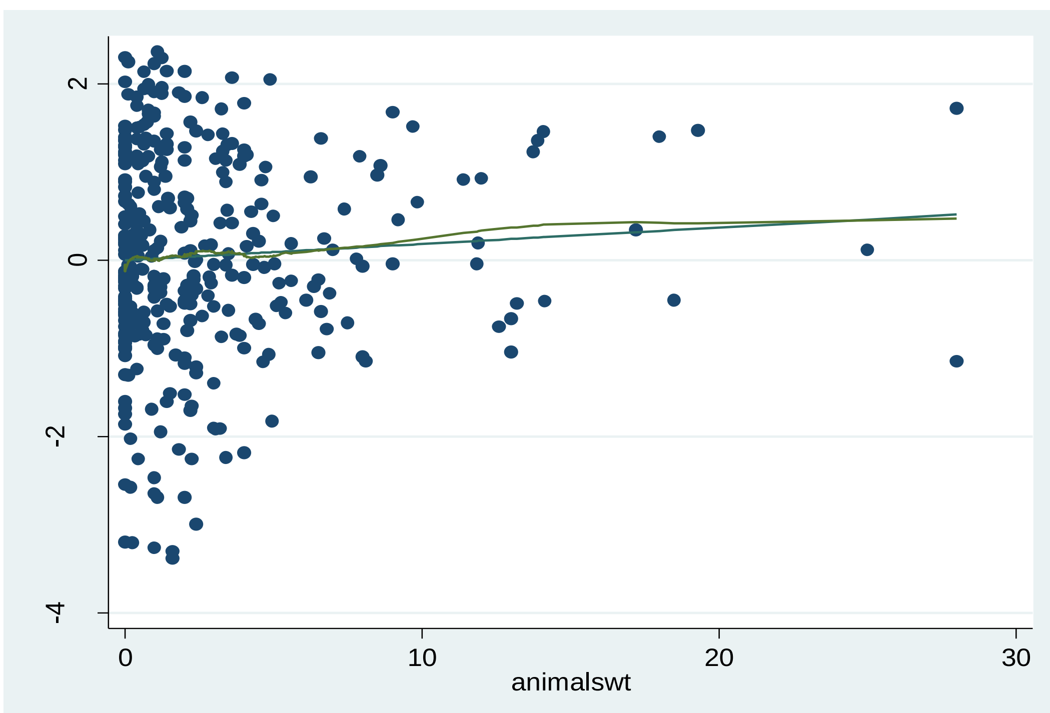


Figure 12: Augmented Component-Plus-Residual Plot for Weighted Value of Animals (*animalswt*)



Heteroskedasticity: A model exhibits heteroskedasticity if the variance of the error term, conditional on the independent variables, varies among outcomes of explanatory variables. We specify the dependent variable with a natural logarithm to mitigate heteroskedasticity. According to Wooldridge (2015), "…when y>0, models using log(y) as the dependent variable often satisfy classical linear model assumptions more closely than models using the level of y." Wooldridge also notes that strictly positive variables often have heteroskedastic or skewed conditional distribution, which is indeed what we observe within our levels of willingness-to-pay. Breusch-Pagan tests provide significant evidence of heteroskedasticity for the model using levels of y (Prob > chi2 = 0.0000) but no evidence of heteroskedasticity for the model using a natural logged dependent variable (Prob > chi2 = 0.7194). This is further evidence that taking the natural log of our dependent variable is an appropriate transformation.

Multicollinearity: A model cannot be estimated by OLS if there is an exact linear relationship between independent variables. No independent variables exhibited high correlations with one another (Appendix 1.2), and a variance inflation factor test (Mean VIF = 1.19) in STATA shows no signs of collinearity (STATA output in Appendix 1.3).

Omitted Variables: Omitting an important variable from our model would violate the Gauss-Markov assumption that error term is uncorrelated with explanatory variables (Wooldridge, 2015). This would cause OLS estimates to be biased and inconsistent. We used a Ramsey RESET test and a link test to detect specification errors. The RESET test "creates new variables based on the predictors and refits the model using those new variables to see if any of them would be significant" (UCLA Statistical Consulting Group). The Ramsey RESET test suggest that we have not omitted any important explanatory variables from our originally specified model (Prob > F = 0.1465). A link test is similar to the RESET test, based on the idea that "if a regression is properly specified, one should not be able to find any additional independent variables that are significant except by chance" (UCLA Statistical Consulting Group). This test creates a variable of prediction (_hat) and a squared variable of prediction (_hatsq), and the model is refit with these two variables as predictors. If a model is properly specified, the prediction variable should be statistically significant and the squared variable should not be statistically significant. We find that neither _hat nor _hatsq are statistically significant (p-values = 0.31, 0.26, respectively), signifying that the model as a whole does not predict our dependent variable.

The link test suggests that our model is misspecified, but due to data limitations, we find no alternative specification that allows the model to pass a link test. Our survey does not contain alternate variables that are believed to affect willingness-to-pay. Dropping or transforming independent variables also has no effect on the link test. No variations in the model yielded significantly different results, and so we chose to report on the hypothesized model that we believed to best fit the OLS assumptions. We also considered running a quantile regression, which would be appropriate if we believed that our independent variables had different effects for farmers across the spectrum of willingness-to-pay responses. Quantile regression has the advantage of being more robust to outliers than OLS and giving a richer characterization of the data. This would seem worth a try given that our OLS model was not significant, but unfortunately, we have too many repeated values in our dependent variable to analyze certain quantiles of our data. A disproportionate number of farmers indicated levels of willingness-to-pay that represent common, simple prices such as 500, 1000, or 5000 CFA, which are roughly equivalent to $1, $2, and $10. Quantile regression is more appropriate in the presence of a smoother distribution of dependent variable values. In the next section, we report results on our hypothesized model and discuss potential reasons for the models' insignificance.

VI.2. Regression Results and Discussion

Through the process of checking the OLS assumptions, we changed our original model by removing multiple outliers and taking the natural log of our dependent variable. Our final model is specified as such:

$$\ln(WTP) = \beta_0 + \beta_{1*}(Age) + \beta_{2*}(NoEdu) + \beta_{3*}(MiddleEdu) +$$

$$\beta_{4*}(Animals)+\beta_{5*}(MilProd)+\beta_{6*}(Severity)+\beta_{7*}(FarmOrg)+\beta_{8*}(Hebetor)+ \mu$$

The OLS regression results are presented in Table 18.

Table 18: OLS Regression Results

Dependent Variable: ln(WTP)				
Independent Variable	Coef.	Std. Err.	T-statistic	P-value
Age	-0.014*	0.005	-3.13	0.002
NoEdu	0.046	0.159	0.29	0.773
Animals	0.019	0.017	1.15	0.252
Milprod	0.000	0.000	1.32	0.187
Severity	0.208	0.201	1.03	0.302
FarmerOrg	0.186	0.180	1.04	0.300
Hebetor	0.007	0.163	0.04	0.967
_Constant	7.562	0.299	25.27	0.000

*p<0.01
Number of Obs = 359
F(8, 346) = 2.15
Prob > F = 0.038
R-squared = 0.041
Adj R-squared = 0.022
Root MSE = 1.173

Age is the only variable that is significant (p=0.002) at any meaningful critical value. In a log-level model (dependent variable is in log form and independent variable is in level form), the coefficient multiplied by 100 is referred to as the semi-elasticity of y with respect to x

(Woolridge, 2015). The -0.014 coefficient on *age* is interpreted to mean that if farmer's age increased by one year, we would expect that farmer's willingness-to-pay for beneficial insects to decrease by 1.4% holding all else equal. This information does not inform any specific intervention, but it could be useful knowledge for business planners. If older people are less willing to pay for parasitoids, businesses may want to focus more of their effort on marketing to older people, assuming that widespread village participation is deemed necessary for creating sustainable cooperative purchasing arrangements.

Overall, the model is a weak predictor of willingness-to-pay. An R-squared value of 0.041 suggests that only 4.1% of sample variation in willingness-to-pay is explained by the model's independent variables. A low R^2 does not mean that the model is useless, as it is still possible that OLS estimates are reliable for explaining each independent variables' ceteris paribus effect on willingness-to-pay (Wooldridge, 2015). However, our model provides no evidence that any of our predictors other than *age* has any effect on willingness-to-pay. The variables of special interest in our model, *FarmerOrg* and *Hebetor*, are insignificant predictors of willingness-to-pay. Based solely on this model, our findings suggest that certain interventions, such as exposing farmers to parasitoids or encouraging farmers to join farmer groups, would not be effective ways to gather farmer support for parasitoid purchases.

Based on a preliminary examination of the survey data, it is not surprising that the variables in our model poorly predict willingness-to-pay. Our chosen predictors have very low correlations with our response variable, and scatterplots comparing predicting variables to the response variable show little to no visual trends in the data (Appendix 1.4). If the Gauss-Markov properties are satisfied, which we believe they are, OLS estimators are considered to be the best linear unbiased estimators (BLUE), but even if our estimators are BLUE, there are several reasons why our model could have no predictive power. It could be the case that our predictor variables truly have no effect on willingness-to-pay. It is curious that neither millet production nor the wealth proxy (*Animalswt*) have a significant positive association with willingness-to-pay, because economic indicators are expected to be strongly related to purchasing power. Perhaps the weighted number of animals is not a good proxy for wealth, but unfortunately, we have no better wealth proxies in our survey data. There are several reasons why the *Hebetor* variable may not have conformed to our hypothesis that previous exposure to the parasitoid is expected to predict greater willingness-to-pay. First, this variable is strongly correlated with the region of farmer residence, so the variable could be picking up geographic effects. Second, about one-quarter of farmers who received *H. hebetor* indicated that the technology was ineffective, presumably due to late release timing. Negative impressions of the technology would likely lower willingness-to-pay. Third, farmers who previously received the technology probably received the technology for free, thereby making these farmers less likely to put money forward for the product. These factors call into question the ability of our *Hebetor* variable to have a positive reflection on willingness-to-pay.

Perhaps a more likely reason why our model has no predictive power is that the willingness-to-pay survey question did not serve its intended purpose of eliciting the real economic value of parasitoids to farmers. As discussed in Section III.4., there are many critics of contingent valuation, and it is possible that asking Nigerien farmers to deduce a value for a relatively unconventional pest control product proved to be an inaccurate valuation technique. Farmers may have indicated completely arbitrary values of willingness-to-pay. Measurement error in the dependent variable can have two effects (Wooldridge, 2015). It will unambiguously inflate variances which decreases the chance of finding significance in the model. Also, it can bias OLS estimates if the measurement error is correlated with any independent variables. Regardless of the correlation between measurement error and independent variables, the OLS model does not provide convincing support for the relative importance of the independent variables in predicting willingness-to-pay if measurement error is indeed present. Given the potential limitations of the model, we are not confident that there is conclusive evidence for or against the relative importance of our chosen variables, and so it is difficult to draw practical business implications from the OLS model results. It is our opinion that the reason that the model has little predictive power is because the survey question did not work as planned. Even if the question had worked, there are limits to what the model could tell us about farmer preferences in the context of cooperative purchases. As mentioned earlier in the paper, the survey question indicated nothing about the public good nature of the *H. hebetor* or that villages would be best served to purchase the bags cooperatively, so in theory, the question should elicit responses that closely resemble the true value of the parasitoid to each individual farmer. Perhaps farmers' WTP would differ if they knew that other members of their villages were contributing. Even if the model was able to associate certain variables with lower levels of willingness-to-pay, this information may not reflect realistic marketplace behavior given that contributions by individual farmers are expected to be very low in cooperative purchases. For example, a -1.4% decrease in WTP associated with a one year increase in age is practicality meaningless if an individual farmer only needs to contribute $0.09 to a cooperative purchase.

Chapter VII. – Discussion and Implications

The idea to start a biological control cottage industry was proposed by scientific researchers at ICRISAT and INRAN who believe that commercialization of beneficial insects is the best way to ensure the sustainability of effective pest control provision for subsistence millet farmers in Niger. Based on initial research about parasitoid effectiveness, optimal parasitoid rearing and release techniques, farmer awareness of pests and parasitoid, and farmer field schools for parasitoid release techniques, researchers were optimistic that *H. hebetor* businesses could be profitable ventures that provide a worthy service for farmers, and in general, the analysis in this paper corroborates this hypothesis. If the assumptions of this study's analysis hold, *H. hebetor* businesses can achieve wide profit margins, provide farmers with an economically beneficial product at a reasonable price, and create jobs with fair wages. The rest of this section will summarize quantitative findings from this study and discuss implications for the future of the biological control industry.

VII.1. Summarized Quantitative Findings

Tables 6, 7, 8, 9, 10, and 14 serve as menus from which businesses can make decisions about sale volume goals, price setting, and wage setting. Profits, wages, and prices are seen as conservative estimates because businesses will receive free start-up equipment and may receive free rooms. A business that sells bags to 13-65 villages could expect first year profits of $50.95 - $1,996.47 if it is not subsidized by research institutions or farmer groups. A business needs to sell a full set of *H. hebetor* to approximately 12 villages to cover its costs and must sell an individual bag at a price between $1.29 and $3.08 to cover the costs of outputting 13-65 bags. The current market price of $3.34 yields profit for businesses with any output greater than 12 village sales. If individual farmers each contribute $0.09 to a cooperative purchasing agreement, a village must contain at least 557 paying households to afford a set of bags at the going rate of $3.34/bag. At $0.17 per household, a village of 295 paying households can afford a set of bags at $3.34/bag. Smaller villages can expect high, but not full, participation rates in cooperative purchases if faced with a bag price of $3.34. If three workers split income equivalent to 10% of bag revenue and a single bag costs $3.34 (which represent current business practices), a business needs to sell to a number of village buyers between 13 and 26 in order to pay workers at least $1.12/day and slightly more than 26 in order to pay workers at least $1.67/day. Farmers who use *H. hebetor* can expect to observe increased yields of 6.3 - 1394 kg depending on their farm size and the effectiveness of parasitoids, corresponding to a value of $2.08 - $460.02. A farm that produces a medium quantity of millet (900 kg) coupled with an average level of pest effectiveness (34%) and an average level of infestation (64%) could expect increased yields of 195.84 kg, corresponding to a value of $64.63.

Our econometric model found that only one variable, *age*, was a significant predictor of WTP for beneficial insects. If a farmer's age increased by one year, we would expect that farmer's WTP for beneficial insects to decrease by 1.4% holding all else equal. We suspect that the main reason why our independent variables were poor predictors of WTP was because our WTP survey question was inherently flawed. Perhaps, a question that elicited WTP responses for various levels of pest control would have been more useful. The econometric model was envisioned as a tool that could provide useful information to businesses about farmers' attitude toward biological control, and despite its potential shortcomings, it is promising for businesses that all who were surveyed indicated a positive WTP.

VII.2. Discussion

If farmers are willing to pay prices consistent with their survey responses, businesses should be able to set prices that mutually benefit all or at least the vast majority of village farmers, thereby preventing incentives to free-ride. Although we are skeptical that the willingness-to-pay survey question elicited values that reflect marketplace behavior, businesses can set prices such that individual contributions to cooperative purchases are much lower than any value of WTP indicated in the survey. The level of farmer participation required to maintain stability of any given cooperative arrangement is unknown, but this study suggests that widespread participation through a cooperative payment system is economically plausible.

Business success is largely contingent upon active networks of communication between businesses, research institutions, government extension agents, farmer organizations, and farmers. The system's effectiveness in helping farmers to reap the benefits of the biological control is reliant upon many different activities by these various actors. Research institutions must provide businesses with thorough training to ensure that businesses know how to breed an adequate supply of *H. hebetor* in a timely manner. Government extension agents must be prepared to provide villages and businesses with timely infestation warnings. Businesses need to connect with villages early in the growing season so that villages can pre-order parasitoids early enough for businesses to have them ready by a certain time. Farmer organizations, government agents, and research institutions also share responsibility for spreading the word about the *H. hebetor* to farmers. Businesses, with the support of research institutions, should organize farmer sensitization sessions in which farmers travel to businesses to be introduced to the concept of biological control. If cooperative village purchases are the desirable sale target, stakeholders must communicate with village leaders who are vital in generating farmer enthusiasm in the parasitoids and implementing a cooperative payment mechanism. Businesses need to build trust among farmers who may not be familiar with biological control, and so, a failure to deliver parasitoids in a timely manner could be a major blow to a business's reputation. A single weak link in this system could result in business failure, so it is important for stakeholders to manage risk with contingency plans. For example, businesses could breed more parasitoids than they need in case another business has a failure in rearing. While businesses get accustomed to rearing practices, ICRISAT and INRAN may also want to continue breeding parasitoids to serve as an emergency solution to rearing failures.

The *H. hebetor* industry was set in motion in 2015, and although businesses had several technical issues, the pilot program was a promising indication that workers can be trained to independently rear *H. hebetor* in a timely manner. Workers suggested that they their businesses will grow and improve in the second year. The pilot program did not provide any insight into the feasibility of farmers cooperatively purchasing parasitoids at the village level, as almost all purchases were made by NGOs. It is a big uncertainty whether the purchasing parties can transition from NGOs to farmers. This study has suggested that cooperative purchases are economically feasible, but these types of purchases will not become a reality without a concerted effort to encourage cooperative purchases and restrict NGO involvement.

References

Aker, J.C., del Ninno, C., Dorosh, P.A., Mulder-Sibanda, M., Razmara, S. (2009). Niger Food Security and Safety Nets. *Social Protection & Labor*. Discussion Paper No. 1418, World Bank Group.

Amadou, I., Gounga, M. E., & Le, G. W. (2013). Millets: Nutritional composition, some health benefits and processing - A review. *Emirates Journal of Food and Agriculture*, *25*(7), 501.

Asiedu-Darko, E. A. (2014). Farmers' perception on agricultural technologies a case of some improved crop varieties in Ghana. *Agriculture, Forestry and Fisheries*, *3*, 13-16.

Ba, M. N., Baoua, I. B., N'Diaye, M., Dabire-Binso, C., Sanon, A., & Tamò, M. (2013). Biological control of the millet head miner Heliocheilus albipunctella in the Sahelian region by augmentative releases of the parasitoid wasp Habrobracon hebetor: effectiveness and farmers' perceptions. *Phytoparasitica*, *41*(5), 569-576.

Ba, M. N., Baoua, I. B., Kaboré, A., Amadou, L., Oumarou, N., Dabire-Binso, C., & Sanon, A. (2014). Augmentative on-farm delivery methods for the parasitoid Habrobracon hebetor Say (Hymenoptera: Braconidae) to control the millet head miner Heliocheilus albipunctella (de Joannis)(Lepidoptera: Noctuidae) in Burkina Faso and Niger. *BioControl*, *59*(6), 689-696.

Baoua, I., Ba, N. M., Ndiaye, M., Dabire, C., Tamo, M. (2009). "Rapport d'activite's du projet de gestion integree de la mineuse de l'epi de mil au Sahel," Unpublished report, McKnight Foundation Collaborative Crop Research Program, Minneapolis, MN.

Baoua, I. B., Amadou, L., Oumarou, N., Payne, W., Roberts, J. D., Stefanova, K., & Nansen, C. (2014). Estimating effect of augmentative biological control on grain yields from individual pearl millet heads. *Journal of applied entomology*, *138*(4), 281-288.

Bhatnagar V. S. (1984). Rapport d'Activite (Novembre 1982-Octobre 1983). Programme de Lutte Biologique. Projet CILSS de lutte integree, Nioro du Rip, Senegal.

Bhatnagar V.S. (1987). Conservation and encouragement of natural enemies of insect pest in dry land subsistence farming: problem, progress and prospects in the Sahelian zone. *Insect Sci Appl* 8:791–795.

Bhatnagar V.S. (1989). Lutte biologique contre la chenille mineuse de l'épi du mil. Sahel PV info 1/2: 5–8.

Blanford, J. I., Kumar, S., Luo, W., & MacEachren, A. M. (2012). It's a long, long walk: accessibility to hospitals, maternity and integrated health centers in Niger. *International journal of health geographics*, 11(1), 1.

Bonabana-Wabbi, J. (2002). *Assessing factors affecting adoption of agricultural technologies: The case of integrated pest management (IPM) in Kumi district, Eastern Uganda* (Doctoral dissertation, Virginia Polytechnic Institute and State University).

Central Intelligence Agency. (2016). Niger. *In The World Factbook*. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/geos/ng.html.

Cheng, W. Y. (1991). Importation of natural enemies for the control of sugarcane insect pests in Taiwan in 1955 to 1989. *Taiwan sugar*.

Cock, M. J., van Lenteren, J. C., Brodeur, J., Barratt, B. I., Bigler, F., Bolckmans, K., Consoli, F.L., Haas, F., Mason, P.G., & Parra, J. R. P. (2010). Do new Access and Benefit Sharing procedures under the Convention on Biological Diversity threaten the future of biological control?.*BioControl*, *55*(2), 199-218.

Euromonitor. (2014). The World Economic Factbook 2014, 21st edition. http://www.euromonitor .com/medialibrary/PDF/Book_WEF_2014.pdf

Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic development and cultural change*, *33*(2), 255-298.

Fernandez-Cornejo, J., Beach, E. D., & Huang, W. Y. (1994). The adoption of IPM techniques by vegetable growers in Florida, Michigan and Texas.*Journal of Agricultural and Applied Economics*, *26*(01), 158-172.

Food and Agriculture Organization of the United Nations. (2015). *FAOSTAT Database Query*, Food and Agriculture Organization of the United Nations, Rome, Italy. Retrieved from http://faostat3.fao.org/browse/Q/QC/E.

Gahukar, R. T., Guevremont, H., Bhatnagar, V. S., Doumbia, Y. O., Ndoye, M., & Pierrard, G. (1986). A review of the pest status of the millet spike worm, Raghuva albipunctella De Joannis (Noctuidae: Lepidoptera) and its management in the Sahel. *International Journal of Tropical Insect Science*,*7*(04), 457-463.

Gahukar, R. T. (1989). Insect pests of millets and their management: a review. *International Journal of Pest Management*, *35*(4), 382-391.

Gahukar, R. T. (1990). Overview of insect pest management of cereal crops in sub-Saharan West Africa. *Indian Journal of Entomology*, *52*(1), 125-138.

Gahukar, R. T. (1992). Effect of various fertilizers and rates on insect pest/pearl millet relationship in Senegal. *Tropical agriculture*, *69*(2), 149-152.

Garba, S., (2000). Lutte biologique contre la mineuse de l'epi Heliocheilus albipunctella De Joannis, avec l'utilisation du parasitoı¨de Bracon hebetor Say, Memoire de fin d'etude, IPRIFRA, Katibougou, Mali.

Guevremont, H. (1981). Etudes sur l'entomofaune du mil: rapport annuel de recherches pour l'année 1980. *Maradi, Niger: Centre National de Recherches Agronomiques de Tarna, Laboratoire d'entomologie*, 31.

Guevremont, H. (1982). Etudes sur la mineuse de l'épi et autres insectes du mil: Rapport annuel de rechèrches pour l'année 1981. *Maradi, Niger: Centre National de Recherches Agronomiques de Tarna Section Protection des Végétaux*.

Guèvremont, H. (1983). Recherches sur l'entomofaune du mil. Rapport annuel de recherches pour 1982. *Maradi, Niger (Centre National de Recherches Agronomiques de Tama, INRAN (Institut national de Recherches Agronomiques du niger*.

Henzell, R. G. (1997). Breeding for Resistance to Panicle Pests of Sorghum and Pearl Millet RG Henzell, GC Peterson, GL Teetes, BA Franzmann, HC Sharma, O. Youm, A. Ratnadass, A. Toure, J. Raab, and O. Ajayi. In*Proceedings of the International Conference on Genetic Improvement of Sorghum and Pearl Millet: September 22-27, 1996, Holiday Inn Plaza, Lubbock, Texas* (No. 97, p. 255).

Holden, N. T., & Nagle, T. (1995). The strategy and tactics of pricing. *Englewood Cliffs*.

International Crops Research Institut for the Semi-Arid Tropics (ICRISAT). (2013). Niger and ICRISAT – Mitigating Poverty, Enhancing Prosperity (Brochure). http://www.icrisat .org/who-we-are/investors-partners/donor-flyers/Flyer%20Niger_A3%2027_8_2013 %20screen.pdf.

Jago, N. (1987). The Return of the Eighth Plague. *New Scientist*, *114*(1565), 47-51.

Japan Association for International Collaboration of Agriculture and Forestry (JAICAF). (2009). Minor Cereals in Niger. http://www.jaicaf.or.jp/publications/niger_e.pdf.

Krall, S., Youm, O., & Kogo, S. A. (1995, October). Panicle insect pest damage and yield loss in pearl millet. In *Proceeding of an International Consultative Workshop on Panicle Insect Pest of Sorghum and Millet, ICRISAT Sahelian Centre, Niamey, Niger* (pp. 135-145).

Leblois, A., Quirion, P., Alhassane, A., & Traoré, S. (2014). Weather index drought insurance: An ex ante evaluation for millet growers in Niger.*Environmental and Resource Economics*, *57*(4), 527-551.

Mankiw, G.N. (2012). *Principles of microeconomics*.

Mariko, D., Malik, & S., Mohamoud, O., (2012). Building Resilience in the Sahel through Cereal Banks. Food for Peace West Africa, Issue #9.

Ministere de l'Agriculture et de l'Elevage Direction des Statistiques (2016). Systeme d'information sur les marches a betail (Flash Info). http://www.reca-niger.org/IMG /pdf/Flash_semaine_du_22_au_28_mars_2016-docbis.pdf, Accessed on May 1, 2016.

Mohamed, A. B., Van Duivenbooden, N., & Abdoussallam, S. (2002). Impact of climate change on agricultural production in the Sahel–Part 1. Methodological approach and case study for millet in Niger. *Climatic Change*, *54*(3), 327-348.

Mooriben. (2012). *Plan Operationnel 2011*. http://www.mooriben-niger.org/IMG/pdf/Rapport_d_activit_2011vf.pdf

Mooriben. (2014). *Qui Sommes Nous?* Accessed at http://www.mooriben-niger.org/IMG/pdf/DEPLIANT_MOORIBEN_2_.pdf

Napit, K. B., Norton, G. W., Kazmierczak, R. F., & Rajotte, E. G. (1988). Economic impacts of extension integrated pest management programs in several states. *Journal of Economic Entomology*, *81*(1), 251-256.

Niger, Institut National de la Statistique (2013). Annuaire statistique-demographie, 2008-2012.

Ndoye, M. (1992). Biologie et dynamique des populations de Heliocheilus albipunctella (de Joannis), ravageur de la chandelle de mil dans le Sahel. *Seminaire sur la Lutte Integree contre les Ennemis des Cultures Vivrieres dans le Sahel. [2. Seminar on Integrated Pest Management of Food Crops in Sahel]. Bamako (Mali). 4-9 Jan 1990.*

Nessim, H., & Dodge, R. (1995). Pricing: policies and procedures. *Houndsmill et al*.

Nordhaus, W. (2015). Climate clubs: overcoming free-riding in international climate policy. *The American Economic Review*, *105*(4), 1339-1370.

Nwanze, K. F., & Sivakumar, M. V. K. (1990). Insect pests of pearl millet in Sahelian West Africa—II. Raghuva albipunctella De Joannis (Noctuidae, Lepidoptera): distribution, population dynamics and assessment of crop damage. *International Journal of Pest Management*, *36*(1), 59-65.

Payne, W., Tapsoba, H., Baoua, I. B., Malick, B. N., N'Diaye, M., & Dabire-Binso, C. (2011). On-farm biological control of the pearl millet head miner: realization of 35 years of unsteady progress in Mali, Burkina Faso and Niger.*International Journal of Agricultural Sustainability*, *9*(1), 186-193.

Samuelson, P. A. (1954). The pure theory of public expenditure. *The review of economics and statistics*, 387-389.

Tijdens, K., Besamusca, J., Ngeh Tingum, E., & Nafiou, M. M. (2012). Wages in Niger: Wage Indicator survey 2012.

Tjornhom, J. D., Norton, G. W., Heong, K. L., Talekar, N. S., & Gapud, V. P. (1997). Determinants of pesticide misuse in Philippine onion production. *Philippine Entomologist (Philippines)*.

UCLA: Statistical Consulting Group. Stata Web Books, Chapter 2 – Regression Diagnostics. Retrieved from http://www.ats.ucla.edu/stat/stata/webbooks/reg/chapter2/statareg2.htm (accessed May 1, 2016).

United Nations Development Programme. (2015). Briefing note for countries on the 2015 Human Development Report, Niger. http://hdr.undp.org/sites/all/themes/hdr_theme/ country-notes/NER.pdf.

Van Lenteren, J. C. (2012). The state of commercial augmentative biological control: plenty of natural enemies, but a frustrating lack of uptake.*BioControl*, *57*(1), 1-20.

Victoria, M. V. (2007). Agricultural Technolongy in Bangladesh: a Study on Non-Farm Labor and Adoption by Gender. (Master's Thesis, Virginia Polytechnic Institute and State University).

Wooldridge, J. M. (2015). *Introductory econometrics: A modern approach*. Nelson Education.

World Bank Agriculture and Environmental Services (AES) Department & Agriculture, Rural Development, and Irrigation (AFTAI) Unit in the Africa Region. (2013). Agricultural Sector Risk Assessment in Niger. http://www.wds.worldbank.org/external/default/WDS ContentServer/WDSP/IB/2013/01/31/000333037_20130131141714/Rendered/PDF/7432 20ESW0P12900Box374318B00PUBLIC0.pdf.

Youm, O., & Gilstrap, F. E. (1993). Life-fertility tables of Bracon hebetor Say (Hymenoptera: Braconidae) reared on Heliocheilus albipunctella de Joannis (Lepidoptera: Noctuidae). *International Journal of Tropical Insect Science, 14*(04), 455-459.

Youm, O., Kumar, K. A., (1995). "Screening and breeding for resistance to millet head miner", in: K. F. Nwanze, O. Youm (eds), Panicle Insect Pests of Sorghum and Pearl Millet, Proceedings of and International Consultation Workshop, 4–7 October 1993, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India, 201–209.

Youm, O., & Owusu, E. O. (1998). Assessment of yield loss due to the millet head miner, Heliocheilus albipunctella (Lepidoptera: Noctuidae) using a damage rating scale and regression analysis in Niger. *International Journal of Pest Management*, *44*(2), 119-121.

Appendix

1.1 Table 19 shows a histogram of willingness-to-pay for beneficial insects. Observations on the right side of the histogram are difficult to see, so a STATA frequency table is also provided to clarify the outlying observations (Table 19).

Figure 13: WTP Histogram

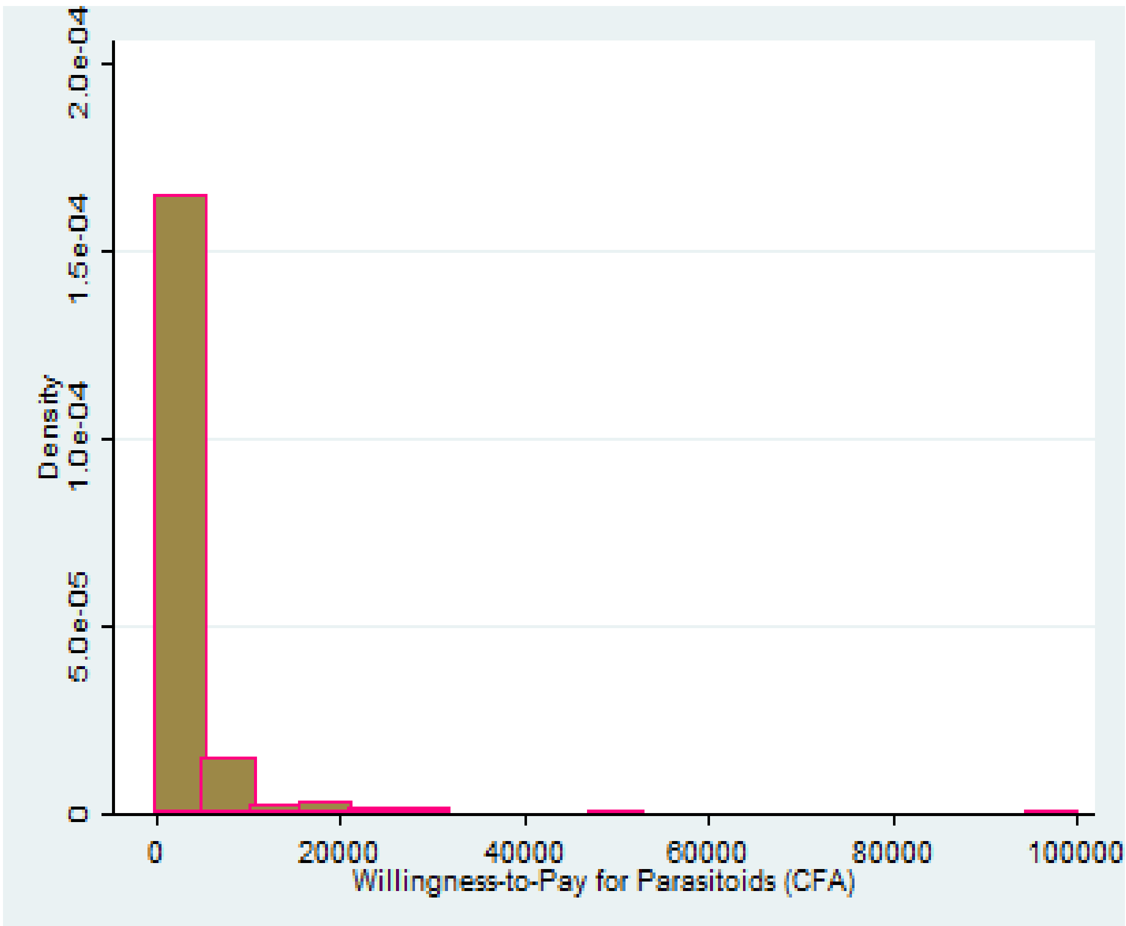


Table 19: WTP Frequency Table

Willingness -to-Pay	Freq.	Percent	Cum.
50	5	1.26	1.26
75	1	0.25	1.51
100	7	1.76	3.27
125	3	0.75	4.02
150	2	0.50	4.52
200	2	0.50	5.03
250	14	3.52	8.54
300	3	0.75	9.30
400	1	0.25	9.55
500	59	14.82	24.37
600	2	0.50	24.87
750	6	1.51	26.38
1000	86	21.61	47.99
1250	2	0.50	48.49
1500	17	4.27	52.76
2000	44	11.06	63.82
2500	17	4.27	68.09
3000	11	2.76	70.85
3500	3	0.75	71.61
4000	6	1.51	73.12
5000	55	13.82	86.93
6000	1	0.25	87.19
8000	1	0.25	87.44
10000	29	7.29	94.72
12000	1	0.25	94.97
15000	4	1.01	95.98
20000	7	1.76	97.74
25000	3	0.75	98.49
30000	3	0.75	99.25
50000	1	0.25	99.50
100000	2	0.50	100.00
Total	398	100.00	

1.2 Table of Correlation between all Variables

Table 20: Table of Correlation

(obs=359)

	lnwtp	age	noedu	animal~t	milprod	sev	farmorg	hebetor
lnwtp	1.0000							
age	-0.1425	1.0000						
noedu	-0.0186	0.2388	1.0000					
animalswt	0.0802	0.0985	0.1391	1.0000				
milprod	0.0661	0.2543	0.0752	0.3763	1.0000			
sev	0.0539	-0.0642	-0.0125	-0.1072	-0.0537	1.0000		
farmorg	0.0552	0.1113	-0.1218	0.1122	0.1829	-0.0244	1.0000	
hebetor	0.0045	-0.0132	-0.0632	-0.1269	-0.0428	0.1696	0.0584	1.0000

1.3 We perform a variance inflation factor (VIF) test to check the model for multicollinearity (Table 21). According to Wooldridge (2015), a VIF value greater than 10 deserves further scrutiny. We find no values close to or above 10. Our independent variables do not appear to be linear combinations of one another.

Table 21: VIF Test

. vif

Variable	VIF	1/VIF
milprod	1.26	0.796265
animalswt	1.21	0.825129
age	1.14	0.873811
noedu	1.11	0.901647
farmorg	1.08	0.929128
hebetor	1.05	0.952217
sev	1.04	0.960141
Mean VIF	1.13	

1.4 Scatterplots of predictor variables vs. response variables (Figure 14-21)

Figure 14: Scatterplot - *Age* vs. Ln(*WTP*)

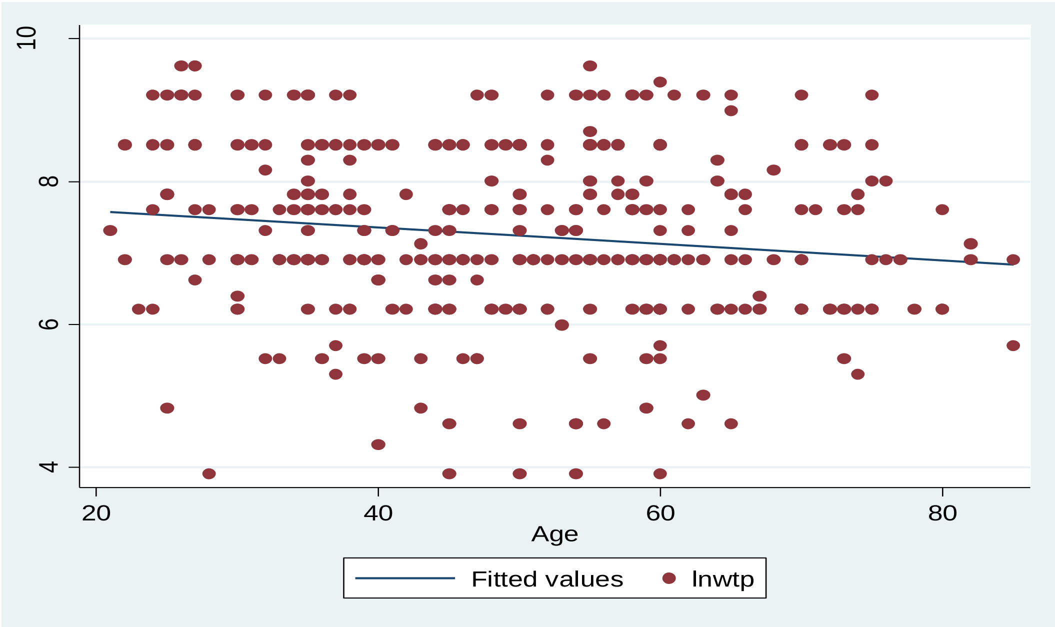


Figure 15: Scatterplot - *NoEdu* vs. Ln(*WTP*)

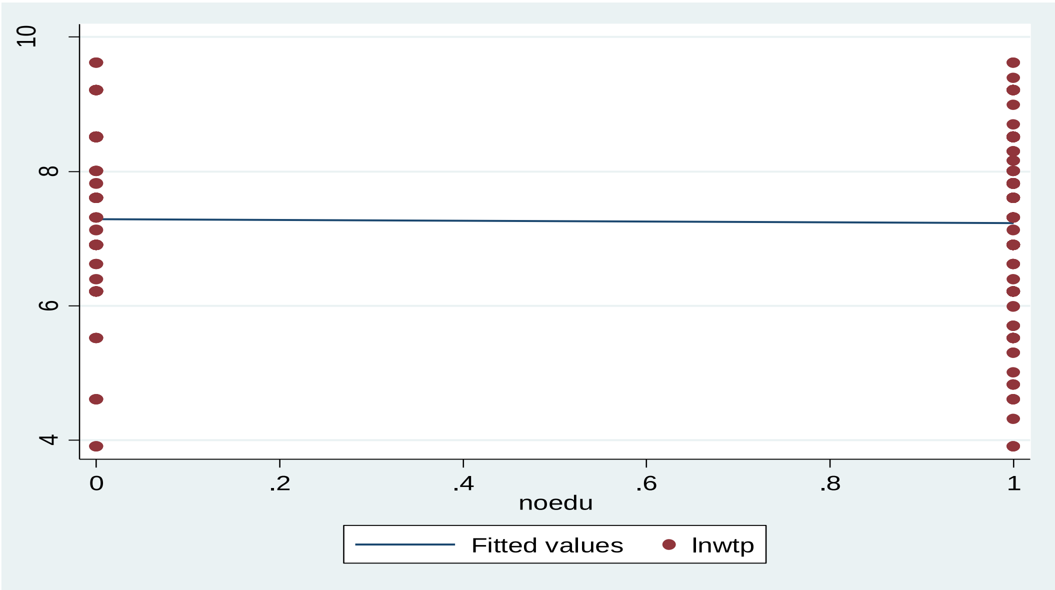


Figure 16: Scatterplot - *MilProd* vs. Ln(*WTP*)

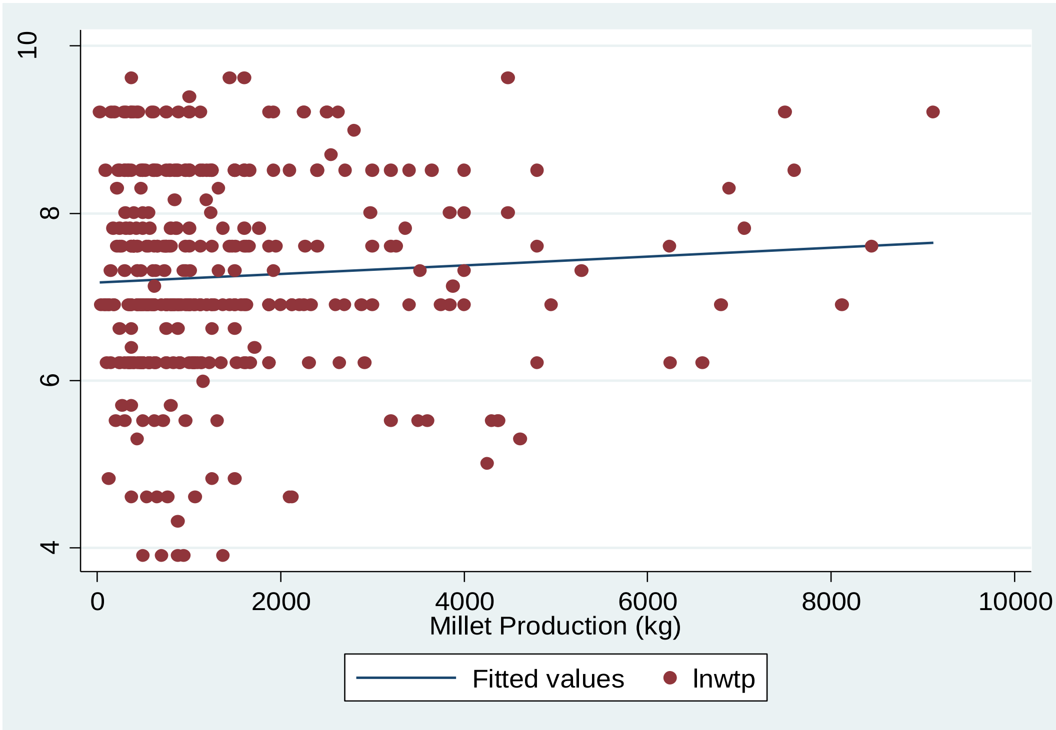


Figure 17: Scatterplot - *Animalswt* vs. Ln(*WTP*)

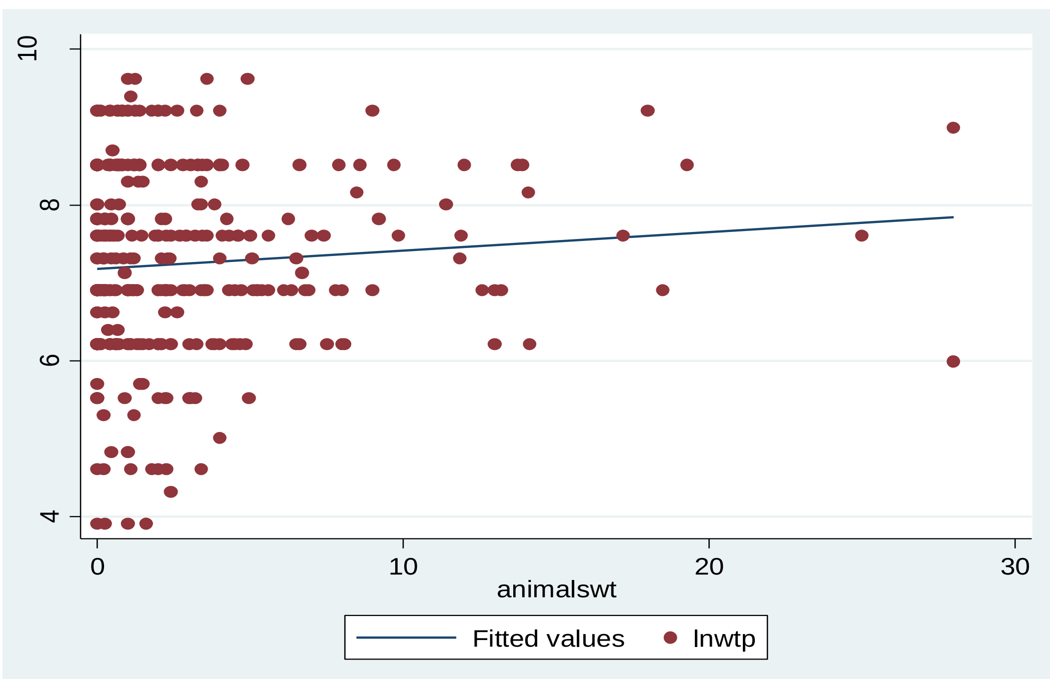


Figure 18: Scatterplot - *Sev* vs. Ln(*WTP*)

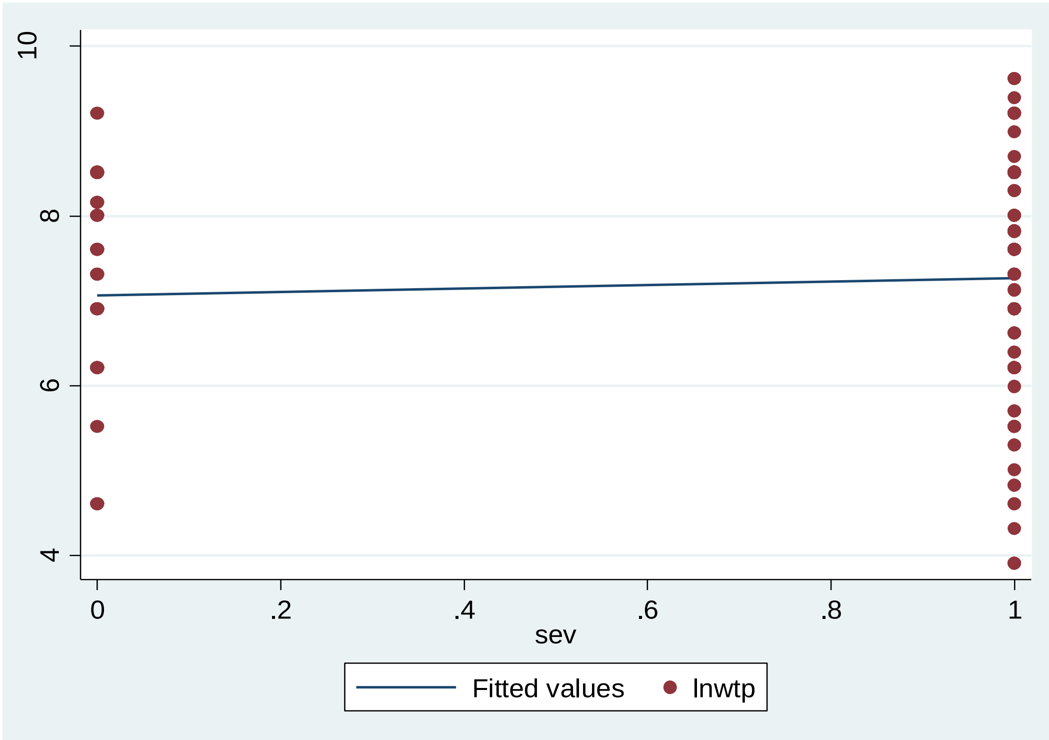


Figure 19: Scatterplot - *FarmOrg* vs. Ln(*WTP*)

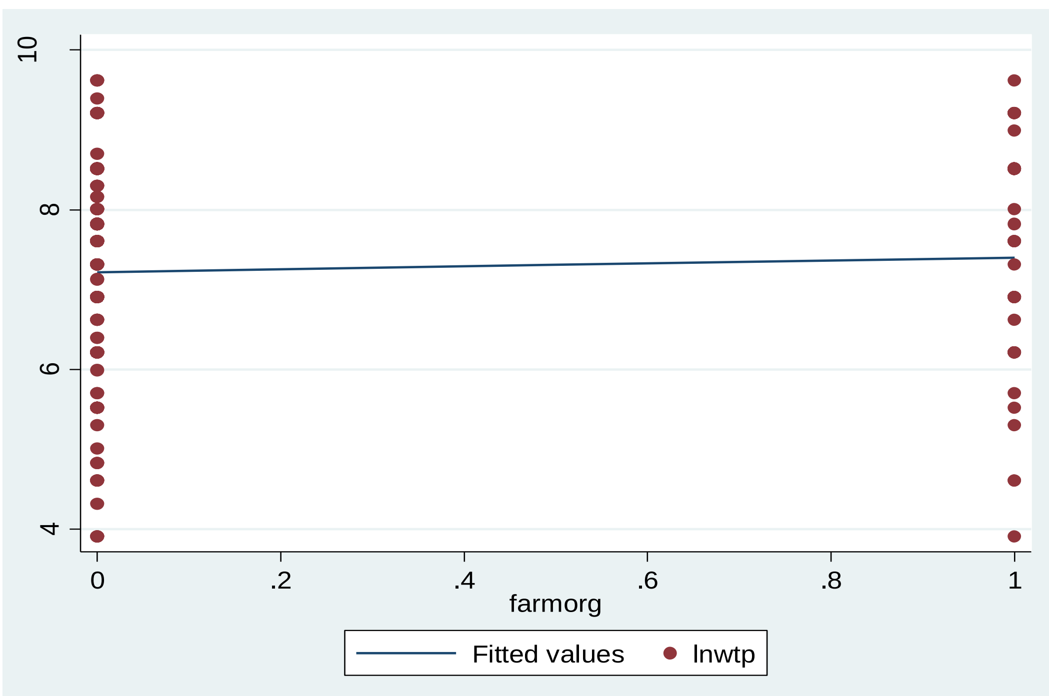
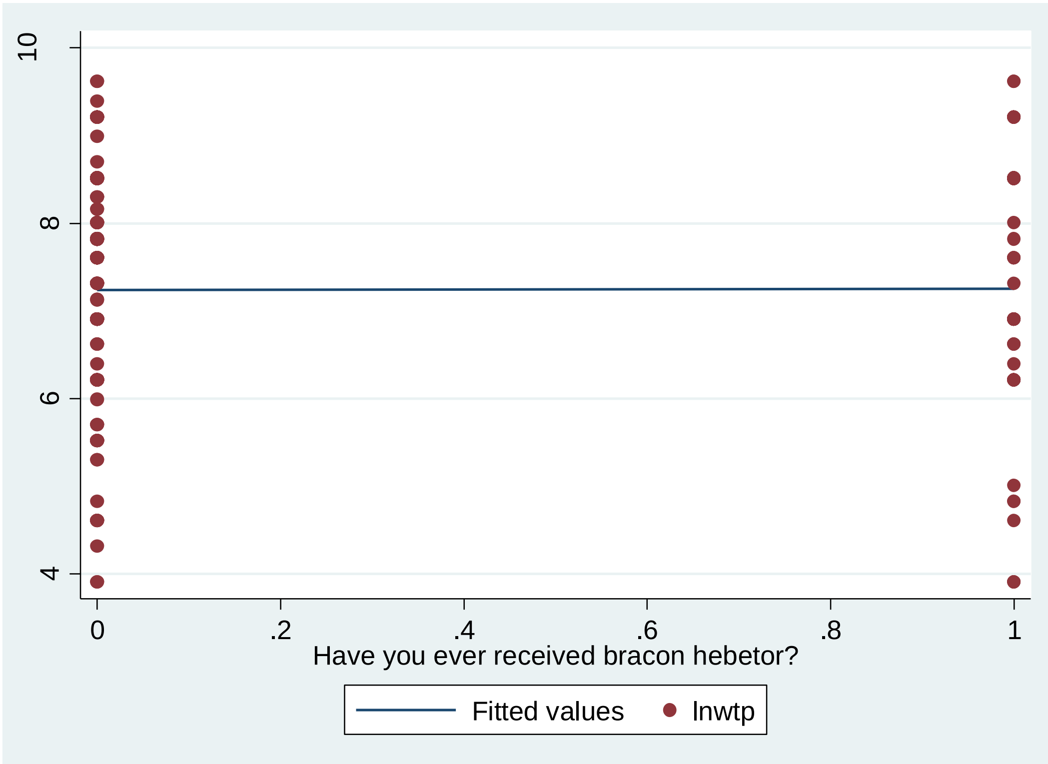


Figure 20: Scatterplot - *Hebetor* vs. Ln(*WTP*)



Farmer Survey

ENQUETE MENAGE DES CULTIVATEURS DU MIL DU NIGER

Salut, je m'appelle --, et je mène des recherches pour le laboratoire d'innovation du sorgho et du mil dont font partie ICRISAT et l'université de Maradi. Nous aimerions vous poser quelques questions à propos de votre ménage, vos pratiques culturales et les problèmes liés aux insectes ravageurs du mil auxquels vous faites face. Seriez-vous prêt à collaborer ? La participation est volontaire et les réponses fournies resteront anonymes et confidentielles.

Nous avons une série de questions qui prendra quelques minutes de votre temps. Etes-vous d'accord pour votre participation ?

№ ménage : --

Nom du répondant : ------------------------------------

Genre : ☐ **M** ☐ **F**

Numéro Cel :

Village : --

Région : ☐ **Maradi** ☐ **Tillabéry**

Enquêteur : ---

Date d'interview : --

Références GPS relatives au champ/maison du répondant

Latitude : -------------------- Longitude : -------------------

I. Situation socioéconomique et démographique

1. Quel est votre âge ?----------------------------
2. Niveau d'instruction : ☐Pas instruit ☐Primaire ☐Collège ☐Lycée ☐Université
3. Etat matrimonial ?

   ☐Célibataire ☐Marié(e) ☐ veuf (ve)
4. Nombre d'épouses : -----------------------------------
5. Nombre de personnes constituant le ménage :

   (a) Homme: ----------------- (b) Femme: -------------------
6. Nombre de personnes ayant plus de 10 ans dans le ménage :

   (a) Homme: ------------------ (b) Femme: --------------------
7. Distance entre votre village et le marché le plus proche (Km) : -------------------------------------
8. Distance entre votre village et la route (accessible par les véhicules) la plus proche (Km) : ---
   ----
9. Superficie des terres cultivées (hectares) l'année passée: --
10. Combien de terres (en hectares) ?
    a. Possession personnelle: ---
    b. Possession commune : --
    c. Terres empruntées : ---
    d. Terres louées à autrui: ---
    e. Jachères : --
11. Possédez-vous des animaux? ☐ Oui ☐ Non ***(Si oui veuillez préciser)***
    a. Bovins? ---------------------------
    b. Moutons ?-------------------------
    c. Chèvres ?--------------------------
    d. Anes ?------------------------------
    e. Chevaux ? -------------------------
    f. Chamelles ? -----------------------

12. Etes-vous membre d'une organisation agricole ? ☐ Mooriben ☐ FUMA Gaskiya

☐ SA'A ☐ Autre: -- ☐ Aucune

II. Production agricole et commercialisation

1. Veuillez citer les principales spéculations de l'année passée, les productions et les superficies correspondantes (hectares)

	Spéculations	Surface cultivée (hectares)	Production		Observation
			Bottes	Kg	
a.	**Mil**				
b.	**Sorgho**				
c.	**Niébé**				
d.	**Arachide**				
e.	**Autres**				

2. Combien ça coute la location d'un ha de terres (champ)***? (veuillez préciser)***

☐ Espèces (FCFA) : ---

☐ Nature (en pourcentage): --

☐ Autre : ---

3. Coût de production du mil

		Nombre d'ouvriers		Nombre de jours	Prix unitaire par jour (prix du village)	Autres formes de paiement
		Familial	Salarial			
a.	**Préparation des terres**					
b.	**Phase de semis**					
c.	**Sarclage ≠1**					
d.	**Sarclage ≠2**					
e.	**Récolte**					

4. Coût des intrants du mil

	Quantité			Prix du marché par unité
	Bottes	**Kg**	**Autres unités de mesure**	
Semence (inclus les stocks)				
Pesticides				
Engrais chimiques				
Fumures organiques				

5. Quel est le pourcentage de consommation du mil au sein de votre famille ?--

6. Pratiquez-vous des cultures de contre saison telles que :

a. Tomate : ☐ oui ☐ non

b. Moringa : ☐ oui ☐ non

III. <u>Parasites et pratiques antiparasitaires</u>

1. Quels sont les principaux insectes endommageant votre mil ?

					Veuillez indiquer qui effectue l'opération en répondant par : – [H] pour homme – [F] pour femme – [T] tous les deux – [G] gouvernement – [P] pas utilisé		
	Insectes		**Ces insectes sont-ils : (répondre par 1,2 ou 3)** 1. **Endémique** 2. **Occasionnel** 3. **Aucun problème**	**Ravage causé par les parasites (échelle de 1 à 3)** 1. **Faible** 2. **Modéré** 3. **Elevé**	**Application de pesticides**	**Guêpe parasite**	**Autre (spécifier)**
a.	**Mineuse du Mil (MHM)**	☐					
b.	**Foreur de tige**	☐					
c.	**Cantharide**	☐					
d.	**Criquets**	☐					

e.	**Hanneton coléoptères**	☐					

2. Si le cultivateur utilise de pesticide, répondre à la question suivante :

Quels sont les pesticides les plus utilisés pour contrôler les insectes ?

Liste de pesticides appliqués		**Nombre d'application par an**
№		
1		
2		
3		

3. Aviez-vous déjà entendu parler de la lutte biologique contre la mineuse du mil ?

   ☐ Oui ☐ Non ***(si non, allez à la question N° 5)***

4. Si Oui, où aviez-vous entendu parler ?

   ☐ Journal/ Dépliant/ Bulletin
   ☐ Radio/ Télévision
   ☐ Démonstration/ Journée porte ouverte
   ☐ Champ/ école
   ☐ Agent de vulgarisation agricole
   ☐ Parent
   ☐ Voisin/ Amis
   ☐ Revendeur de pesticides
   ☐ Autre (spécifier): ---

5. Avez-vous entendu parler du *bracon hebetor* ? ☐Oui ☐Non

(Si non, aller à la question 13)

6. Avez-vous déjà reçu *bracon hebetor* ? ☐Oui ☐Non

7. Si oui, de qui l'avez-vous reçu ? ---

8. Avez-vous déjà acheté le *bracon hebetor* ? ☐Oui ☐Non

9. Si oui, ou l'avez-vous acheté ?---

10. Est-ce quelqu'un de votre village a déjà acheté ou reçu du *bracon hebetor* ? ☐ Oui ☐ Non

11. Si oui, de qui l'a-t- il- reçu ? --

12. Est-ce que les parasitoïdes permettent de limiter les pertes en rendement de mil ?

    ☐Oui ☐ Non

13. La mineuse du mil est un ravageur qui cause des dégâts au mil. Le control biologique qui consiste à utiliser un insecte bénéfique dénommé *bracon hebetor* permettra de lutter contre cette mineuse. Ces insectes bénéfiques sont utilisés dans des sacs ***(un sac contient 80 bracons hebetor)*** et placés dans les champs. Combien seriez-vous prêt à payer pour un sac de *bracon hebetor* afin de contrôler les dégâts de la mineuse du mil (MHM) ? --

Note on Currency Conversion:

All dollar figures in this paper are based on the exchange rate of CFA (XOF) to USD on June 1, 2015. The paper was originally written using CFA values, and these CFA values were subsequently converted to US dollars. Because of this conversion process, using basic mathematical operations (adding, subtracting, multiplying, and dividing) to manipulate dollar figures in this paper may yield slightly different numbers than are presented in this text.