Adoption Determinants and Impacts of *Tuta absoluta* Integrated Pest Management for Nepali Tomato Farmers

Lauren M. Knaresboro

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

Ford Ramsey

August 6th, 2019

Blacksburg, VA

Keywords: Nepal, Integrated Pest Management, *Tuta absoluta*, tomatoes, adoption, pesticide use

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Academic Abstract

Tuta absoluta, a member of the moth family, causes devastating yield loss to tomato farmers around the world. Its recent migration into the tomato fields of Nepal puts tomato farmers at a high risk of yield loss. In response, chemical pesticide use by Nepali farmers is increasing. Integrated pest management (IPM) practices have been implemented in hopes of reducing the frequency of chemical pesticide use while controlling yield risks. This study examines the extent and determinants of *Tuta absoluta* IPM adoption and its effect on the frequency of pesticide use for Nepali tomato farmers. Primary data was collected from four-hundred and one households in four districts throughout Nepal. Two levels of IPM practices were assessed, simple and complex, based on the need for additional knowledge and tools. An instrumental variable probit analysis was used to analyze the determinants of IPM adoption. Household distance to nearest agricultural extension office was a significant factor decreasing the likelihood of the adoption of complex practices. Amount of land dedicated to tomato production, membership status of the primary decision maker, IPM training regarding *Tuta absoluta* practices and severity of *Tuta absoluta* were found to increase the likelihood of the adoption of complex practices. In order to analyze pesticide use, a simple linear regression was used. Primary decision maker's age, gender, and education level were significant determinates to decrease the amount of expenditures spent on chemical pesticides to control for *Tuta absoluta*. IPM adoption level, amount of land dedicated to tomato production and severity of *Tuta absoluta* damage were significant determinates to increase the amount of expenditures spent on chemical pesticides to control for *Tuta absoluta*.

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General Audience Abstract

Tuta absoluta, a member of the moth family, causes devastating yield loss to tomato farmers around the world. Its recent migration into the tomato fields of Nepal puts tomato farmers at a high risk of yield loss. In response, chemical pesticide use by Nepali farmers is increasing. Integrated pest management (IPM) practices have been implemented in hopes of reducing the frequency of chemical pesticide use while controlling yield risks. This study examines the extent and determinants of *Tuta absoluta* IPM adoption and its effect on the frequency of pesticide use for Nepali tomato farmers. Data was collected from four-hundred and one households in four districts throughout Nepal. Different economic tools were used to conduct the analyses. Results show the farther a household is to the near agricultural extension office, the less likely a household is to adopt complex practices. An increased amount of land dedicated to tomato production, the primary decision maker being a member of a marketing or community organization, the primary decision maker having attended IPM training regarding *Tuta absoluta* practices and the greater the severity of *Tuta absoluta* in the household tomato fields, the more likely a household is to adopt complex practices. Contrary to one of the goals of IPM practices, this study shows complex adopters use more chemical pesticides than simple adopters. Results this study shows a need for further education of the relationship between IPM practices and the use of chemical pesticides.

Acknowledgements

To Dr. George Norton, thank you for trusting in me and believing in me to be a part of this project. All of your words of wisdom and encouragement truly helped me not only move forward with each step of the project but also with every step of graduate school. Thank you for being a such a wonderful mentor and role model.

A special thank you to USAID and the Center for International Research, Education, and Development (CIRED) for funding and conducting this project. It has allowed me to learn and experience more than I ever imagined I would during my time in graduate school.

Thank you to my committee members, Dr. Alwang and Dr. Ramsey, for all the time spent helping me further my education. Your advice and encouragement helped me through many speedbumps throughout these past two years. To Dr. Lachocelle and Kate, thank you for taking time out of your busy schedules to help me with my analysis.

Thank you to Luke, Lalit, Muquti, Raun, and every else in the iDE Nepal team. Without you all, I could not have completed this project. Thank you for making me feel comfortable and taken care of during my time in Nepal. A special thank you to Lalit for continuously sharing needed data and information throughout the year. To my enumerators, Anu, Anita, Divya, Zyoti, thank you all for not only helping distribute my survey but for showing me all Nepal has to offer. To all the Nepali farmers who participated in this survey, thank you for your time and contribution. I hope you all benefit from this project.

To my parents, Dan and Patty, thank you for all the love and support during this period of my life. Thank you for believing in me and for all the comfort you provided. I could not have done this without you both. To my brother Brennan, thank you for all the laughs and support throughout these past two years.

To my fiancé, Aaron, thank you for supporting me throughout every step of my life, especially graduate school. From comforting me during my struggles to celebrating with me during my victories, you were always there to encourage me. Thank you for being my strength and my rock.

To Krista, thank you for being an awesome support system during these past two years. Your encouragement and understanding are one of the reasons I made it to this point.

To all my professors and friends within the Agricultural and Applied Economic Department, I will be forever grateful for all your support and advice throughout these past two years. It is so nice to work in an environment where everyone wants you to succeed and move forward in life. I wish you all the best wherever life may take you.

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Chapter 1: Introduction

1.1 Problem Statement

The world economy and population continue to develop and grow at an unprecedented rate. The global population is expected to reach nine and a half billion people by 2050 (World Bank Group, 2018a). The majority of this economic and population growth will occur in developing countries. Asia alone expects to grow by one billion people (Bureau, 2018). Nepal, one of the poorest countries in South Asia, has seen its population almost triple from ten million people to twenty-eight million people in the past sixty years (World Bank Group, 2018b). In 2017, the population of Nepal totaled 29,304,998 with a growth rate of 1.11 percent (World Bank Group, 2018b). A major challenge with the rapidly increasing population in developing countries like Nepal is ensuring food security.

Nepal's economy and population relies heavily on domestic agriculture. The agricultural sector contributes to twenty-seven percent of the national gross domestic product (GDP) (World Bank Group, 2018b). Not only does domestic agriculture contribute to feeding the population, it also employs the majority of the population. Seventy-two percent of employed Nepali citizens work in the agricultural sector. Even though the majority of the employed population is producing food, a rapidly increasing population jeopardizes food security. Relatively small farm sizes (an average size of 0.036 hectares) and an increasingly unpredictable climate are just a few potential limitations to food security (Nations, 2018a). While these factors are almost impossible to control, producers can improve their ability to adapt to change through market based processes. Greater food production and increased purchasing power by the poor will be required to ensure food security.

Although a relatively poor nation, Nepal's gross national income per capita grew from around $50 constant 2017 US dollars in 1960 to around $800 constant 2017 US dollars in 2017. Studies have shown that as income increases, demand for vegetables grows (Schreinemachers, Simmons, & Wopereis, 2017). Tomato consumption in Nepal is on the rise. In 2016, 340,493 metric tons of tomatoes needed to be produced per year to meet the domestic tomato demand (Ghirmirem Kandel, & Bhattarai, 2017). This is up from 335,691 metric tons per year in 2015. Tomatoes are an important vegetable crop in the Nepali diet and can be found on almost every kitchen table. In 2010, a study focused on Nepali tomato production and consumption showed that 57 percent of tomato production was consumed by producers themselves while 43 percent entered the market (Ghirmire et al., 2017). As Nepal's agricultural sector and demand for tomatoes grew, an uncontrollable set back arrived in the tomato fields of Nepal.

Tuta absoluta, an invasive leaf miner, spread from Africa to India in 2015 and made its way into the tomato fields of Nepal in 2016. *Tuta absoluta* has the ability to destroy entire fields of tomatoes. It originated in South America and then traveled to Europe and Africa before arriving in South Asia (Desneux et al., 2010). It has now infested at least twenty-three out of seventy-seven districts within Nepal (Nepal, 2017a). This leafminer lays eggs on the underside of the leaf and/or stem of the plant, the eggs hatch, and the caterpillars feast on the leaf and fruit of the tomato plants (Desneux et al., 2010). Female leafminer moths can lay around two-hundred and fifty to three-hundred eggs per generation. These leafminers can then produce new generations ten to twelve times a year. They invade tomato fields at a high rate. The plants that are affected by these pests can be completely destroyed, leaving farmers with a devastating yield loss. These yield losses impact more people than just farmers. *Tuta absoluta* has the ability to severely damage the Nepali tomato market. As supply in the market decreases, tomato prices rise

which results in a decrease in the quantity demanded. Reduced yields place farmer profits in jeopardy.

In an attempt to lower the population of *Tuta absoluta* and prevent major yield loss, tomato producers have begun applying greater quantities of chemical pesticides to their fields. Using chemical pesticides as a method for controlling pests is not a new method for Nepali farmers. Pesticides were first introduced in Nepal in the early 1950s to control for malaria (Sharma, Thapa, Manandhar, Shrestha, & Pradhan, 2012). Many more chemical pesticides have since arrived in Nepal and been applied by farmers. Without proper training and education, farmers use greater pesticide quantities and improperly apply them to their crops regardless of the health and environmental damages those actions can cause (Karmacharya, 2012). Applications of high pesticide amounts have been recorded in vegetable production in Nepal (Atreya, Johnsen, & Sitaula, 2012). One study calculated the marginal productivity of these pesticide applications to be close to zero (Jha & Regmi, 2009). Improper application or overuse of chemical pesticides can lead to multiple health and environmental effects as well as pest resistance. Many Nepali farmers are unaware of the risks involved with improper pesticide application (Palikhe, 2002).

Organochlorine insecticides, highly toxic pesticides, are still in use in Nepal and other developing countries despite their ban in most developed countries (Sharma et al., 2011). These pesticides are known to have carcinogenic effects in humans. An over application of these and other pesticides can lead to a multitude of health problems, including but not limited to; birth defects, cancer, and neurotoxicity (Alavanja, Hoppin, & Kamel, 2004). Despite farmers having seen the health effects of these toxic pesticides, many continue to over- and mis-using them. The health of the environment is also put at risk. Although a pesticide application is usually targeted

at a small piece of land or specific crop, the chemical can easily spread to surrounding areas by natural carriers (Pimentel, 1995). Lastly, an overuse of pesticides can lead to pests adapting; this resulting in pesticide resistance (Mallet, 1989). Farmers then apply an even greater quantity of pesticides to combat the increase of these adaptive pests. A vicious cycle of over application then occurs.

One approach to minimizing chemical pesticide use is integrated pest management (IPM). The Food and Agriculture Organization of the United Nations describes IPM as a pest management approach that uses multiple strategies to reduce pests, promote healthy crops, and reduces the amount pesticides applied (United Nations, 2018b). IPM was first introduced to the world about sixty years ago (Harris, 2001). Primarily in more developed countries, researchers began researching and developing IPM systems that reduced pest losses while minimizing the use of chemical pesticides on field crops by reducing calendar-based sprays and encouraging use of biological control agents. IPM was not introduced in developing countries until the 1980's (Peshin, Jayaratne, & Sharma, 2014). It was first introduced to South Asia to help reduce pest outbreaks in rice. The IPM approach has spread slowly, however, and pest problems and pesticide use continue to grow in developing countries.

In order to combat current and prevent future *Tuta absoluta* issues, multiple IPM projects have been implemented through a concerted effort by Nepali institutions, led by the USAID-supported Feed the Future the IPM Innovation Lab (IPM IL). The IPM IL began work in Nepal in 2008. It has successfully accomplished several goals. In collaboration with Nepali institutions, it has developed IPM packages for high-value vegetable crops, reduced the amount of toxic pesticides used on farms, transferred IPM technology, and conducted long-term trainings and workshops to educate farmers about IPM (Lab, 2018). Current challenges it faces are the overuse

of chemical pesticides and the loss in biodiversity. The current project focuses in part on combating current and future yield loss from *Tuta absoluta* using IPM practices. By providing workshops, training, and providing assistance through a network of community business facilitators (CBFs), IPM packages were distributed to a group of tomato farmers in select villages. Practices in the IPM package include pheromone traps, light traps, biopesticides, netted nurseries, net houses with doors, destroying previous crops, limiting a variety of host plants, and checking seedlings for *Tuta absoluta* before planting (Nepal, 2017b).

Full adoption of these IPM practices should help the control of *Tuta absoluta* in Nepal. To date, only a portion of tomato farmers have adopted these IPM practices. This does not come as a complete surprise as previous studies in developing countries have also seen new IPM practices only implemented by farmers partially or gradually (Parsa et al., 2014). Pesticides are still in use; it is unknown if adoption of these IPM practices decreases the frequency of pesticide applications on tomato fields (Sharma et al., 2012). This project aims to answer these questions by examining the extent of IPM adoption, examining what factors influence adoption of IPM practices and comparing the frequency of pesticide use between adopters and non-adopters.

1.2 Objectives

The purpose of this study is to conduct an adoption analysis of *Tuta absoluta* IPM practices in Nepali tomato farms. Specific objectives are to:

1. To determine the extent of adoption of IPM practices applied to manage *Tuta absoluta* in major tomato growing districts in Nepal and factors that influence adoption of those practices.
2. To compare the frequency of pesticide use for *Tuta absoluta* by tomato farmers who adopt *Tuta absoluta* IPM practices with frequencies by farmers who do not adopt the

practices.

1.3 Organization of Thesis

This thesis is divided into five chapters. Chapter 2 covers background information of Nepal, *Tuta absoluta*, and pest control methods. Chapter 3 discusses the conceptual framework of this project, variable descriptions, and model construction. Chapter 4 presents the descriptive statistics and results of the models discussed in Chapter 3. It also presents a discussion of the results. Chapter 5 concludes with a summary, policy implications, limitations, and extensions of this study.

Chapter 2: Background and Literature Review

2.1 Nepal Geography, Demographics, and the Economy

Figure 2.1: Map of Nepal

US CIA, 2019

Nepal is a land-locked country located in Southern Asia. It is situated between China to the North and India to the East, South, and West (US CIA, 2019; World Atlas, 2019). The terrain in Nepal is widely diverse. It can be divided up into three different regions. The land along the southern border of Nepal is referred to as the Tarai Region (World Atlas, 2019). This terrain is defined by flat plains containing the lowest points in Nepal (World Atlas, 2019). Moving to the North, the elevation begins to rise and the Hill Region begins. Mountains that are not snowcapped year round are referred to as the Hills (World Atlas, 2019). This region has a range of elevations from 1,968 feet to 9,842 feet (World Atlas, 2019). The last region is considered the Mountainous or Himalayan Region (World Atlas, 2019). This region is located at the Northern most portion of Nepal and contains all the remaining mountains that are snowcapped year round. These mountains are part of the Himalayan mountain range where elevations can reach to heights

of 29,035 feet (World Atlas, 2019). The average elevation throughout the country is 2,565 meters (US CIA, 2019). The climate differs between regions. Summers in the tarai are generally subtropical while cool summers exist in the mountainous region (US CIA, 2019). Winters have a similar pattern in which they are mild in the South and severe in the mountainous regions (US CIA, 2019). Nepal has 143,351 square kilometers of land and only 3,830 square kilometers of water (US CIA, 2019). Of that land, 28.8 percent is devoted to agriculture (US CIA, 2019).

Of a population of 29,717,000 people, the majority live in the tarai and hills regions (US CIA, 2019). 37 percent are between in ages of 25 and 54 with a median age of 24.5 years. The country has a population growth rate of 1.09 percent and a migration rate of negative 2.2 migrants per one thousand people (World, 2019; US CIA, 2019). This migration rate indicates emigrants are leaving Nepal. Life expectancy is 71.3 years (US CIA, 2019; World, 2019). The official language is Nepali but the majority of the government and business population speak English. 81.3 percent of the population practice the Hindu religion while an additional 9 percent practice Buddhism. The literacy rate is 63.9 percent (US CIA, 2019). There is a high degree of risk of infectious diseases (US CIA, 2019).

The Nepalese gross domestic product (GDP) is currently stated at 79.19 billion US dollars with a growth rate of 7.9 percent (US CIA, 2019). Of that GDP, 27 percent is the result of agriculture while services contribute 59.5 percent. These percentages differ from the percentage of labor force. Agriculture employs 69 percent while services only employs 19 percent. At a per capita level, the gross national income averages at 2,700 US dollars. The unemployment rate has been fluctuating around 3% for the last few years (US CIA, 2019). Of the population of nearly 30 million people, approximately one fourth live below the poverty line. The country is heavily reliant on remittances from other countries (US CIA, 2019).

With 23 percent of the land in Nepal purposed for agriculture and 69 percent of the labor force contributing to agriculture, the agricultural sector in Nepal indirectly and directly impacts a large portion of Nepali citizens.

2.2 Tomato Consumption and Production in Nepal

In order to continue to grow the agricultural sector, producers must invest in the production of high value crops. Though it may involve greater risks, vegetable production can result high value, commercial crops. Ghimire, Kandel, Aryal, and Bhattarai (2017) state:

> Different promotional campaigning for the commercial production of vegetables has been initiated by government as well as private sector to increase the income of farmers and generation of employment opportunities at rural areas of the country [Nepal] resulting into significant increment of vegetable production. (p. 84)

One prominent high value vegetable crop is tomatoes. In Nepal, tomato consumption is rapidly increasing (Ghimire, Kandel, Aryal & Bhattarai, 2017). In 2014, the average tomato consumption per person was 11.97 kilograms per year with the average slightly varying by region (Ghimire et al., 2017). Of that consumption, 21.8 percent is sourced from home production while 78.2 percent is purchased (Ghimire et al., 2017). Nepal is a small importing country in terms of tomato trade. Less than one percent of their production is exported to India while approximately 13 percent is imported from India (Ghimire et al., 2017). Studies have shown that as income increases, demand for vegetables increases (Schreinemachers, Simmons, & Wopereis, 2017).

Two main types of tomatoes are produced in Nepal. Large plump tomatoes, such as Heirloom tomatoes, are frequently purchased by the service industry (Ghimire et al., 2017). These tomatoes are commonly used by restaurants for salads and other entrée meals. The more popular tomatoes are those similar to Roma tomatoes (Ghimire et al., 2017). These smaller tomatoes are tougher and heartier than the large varieties and see more use in households.

Because of a growing population and an increase in vegetable consumption, tomatoes are in high demand. High market demand pushes producers to invest in tomato production in order to increase farm profits. Nepalese producers have a comparative advantage in growing tomatoes due to the wide range of agro-climate and topographical conditions within Nepal (Ghimire et al., 2017). Producers located in the Tarai region typically grow tomatoes in the autumn/winter months, November through March. Producers located in the hills and mountainous regions grow their tomato crops in the summer/monsoon months, May through September. Producers in the hills have a comparative advantage during the winter months as tomato production in the market place is in its off season so market prices are high. Most tomato production in Nepal occurs in the hills region (146,778 metric tons) followed by the tarai (113,613 metric tons) (Ghimire et al., 2017). Over the past 30 years, tomato production has seen an increase in quantity and yield. In 1991, Nepal produced 1.13 metric tons of tomatoes using 140,500 ropani of land (Ghimire et al., 2017). A ropani, or roughly 508.7 square meters, is a unit of area measurement commonly used in regions throughout Nepal (Rowlett, 2000). That results in a yield per ropani of 8028 kilograms. Fast forward to

2013, 3.42 metric tons of tomatoes were produced using 254,900 ropani of land, which equals 13,419 kilograms per ropani (Ghimire et al., 2017).

There are many methods to produce tomatoes. In the tarai, it is popular for farmers to produce tomatoes in an open field setting. In the hills and mountain regions where tomato production is most popular in the summer/monsoon season, tomato production in plastic houses, otherwise known as polyhouses, is also popular. These houses are open-sided structures with plastic roofing. Figure 2.2 below shows an example. They protect the plants from harmful weather while still allowing sufficient rain and sunlight onto the plants. While they can be beneficial to producers by reducing weather related yield risks, they also come with a high input cost.

Figure 2.2: Tomato Production using a Polyhouse

Source: Photo taken by Lauren Knaresboro, 2018

Tomato production can be costly. With seeds, fertilizer, pest management practices, irrigation, and labor to purchase, farmers make a serious investment into their production. Many farmers need to borrow money in order to start their tomato fields. Even though the initial costs of production can be costly, the tomatoes return on investment can be significant.

The average farm gate price, the price a farmer would receive from a local collector or middleman in 2015/16 was 20.25 Nepalese rupees per kilogram (approximately $0.24 US dollars). Tomatoes then go from collectors, to wholesalers, and finally to retail markets. During these transfers, there are large transportation costs and storage losses. Ghirmire, Kandel, Aryal and Bhattarai (2017) state that there is an approximate five percent storage loss at each of the four levels of the tomato market. Due to these factors, average tomato prices at the retail level are more than double the price at the farm gate.

With the high input costs of tomato production, any threat to tomato production leads to a direct threat to a farmer's income. Unfortunately, a new agricultural pest has become a large threat to Nepali tomato fields.

2.3 *Tuta absoluta*

2.3.1 Origin

Tuta absoluta is a member of the Gelechiidae family, a family of moths (Desneux, Luna, Guillemaud, & Urbaneja, 2011). It is commonly known as *Tuta*, the tomato pinworm, or the tomato leafminer. *Tuta absoluta* originated in South America (Campos, Biondi, Adiga, Guedes & Desneux, 2017). Approximately 12 years ago, *Tuta* arrived in Spain and has since migrated throughout Europe, Africa, the Middle East and Southern Asia (Campos et al., 2017). *Tuta*

absoluta was first confirmed near Kathmandu, the capital of Nepal, in 2016 (Bajracharya, Mainali, Bhat, Bista, Shashank & Meshram, 2016). It is believed that the pest entered the country through tomatoes imported into the Kathmandu valley from India (Bairacharya et al., 2016). Because they are able to fly several kilometers, it is then assumed that the pest flew to the surrounding Kathmandu valley. As for farther regions of Nepal, it is assumed *Tuta* traveled with the assistance of human intervention through trade and transportation. With the rapidly growing *Tuta* population, Nepali tomato farmers are put in a potentially drastic position.

2.3.2 Description

Adult *Tuta* can be identified by their grey/silver pattern with black spots throughout their forewings (Bajracharya et al., 2016; Desneux et al., 2010). A picture of an adult *Tuta absoluta* can be found below in Figure 2.3. The average body length of the adults is five to seven millimeters long with a wing span of eight to ten millimeters (Bajracharya, et al., 2016). Adults can be found resting on leaves of tomato plants during the day (USDA-APHIS, 2011). Mating usually occurs during their most active times; dawn and dusk. Both adult genders are known to mate several times throughout their adulthood. Adult female *Tuta* are known to lay their eggs one by one throughout the day rather than in large amounts (USDA-APHIS, 2011). They generally lay their eggs on the leaves of the tomato plant but have been observed to lay eggs on other parts of the plant as well. During their lifetime, females can lay up to 260 eggs (AIRCA, 2016).

Eggs generally hatch in the morning (USDA-APHIS, 2011). As soon as they hatch, the larvae begin to feed on the tissue of the plant by burrowing mines throughout the leaves and stems. They continue to burrow through the plant, eventually making it to the tomato fruit as the fruit begins to form. The larvae will eventually mature into caterpillars and begin walking on the

exterior of the leaves and plant. They will then create a cocoon in order to pupate. Pupation may occur on any part of the plant including the surrounding soil. A picture of a *Tuta absoluta* larvae can be found below in Figure 2.4.

The average duration of development of these pests widely varies depending on temperature (Barrientos, Apablaza, Norero & Estay, 1998). The higher the average temperature, the faster the development cycle. The wide variety of climates in Nepal allow *Tuta* to develop throughout the entire year. Depending on the temperatures, these pests have the ability to successfully reproduce between ten and twelve complete generations (AIRCA, 2016). Thus the population of *Tuta* can grow rapidly causing major problems in Nepali tomato fields.

Figure 2.3: Adult *Tuta absoluta*

Nepal, 2017a

Figure 2.4: *Tuta absoluta* larva

Nepal, 2017a

2.3.3 Damage

The larvae of *Tuta absoluta* is the main culprit for tomato plant damage (USDA-APHIS, 2011). When eggs hatch, they begin feeding on the surrounding leaves or shoot of the tomato plant. They will burrow between the layers of the leaves leaving the plant at a loss of surface area to allow photosynthesis to take place (Desneux et al., 2010). As they grow, they work their way through the remainder of the plant, including the tomato fruit. Once the fruit begins to develop, mature *Tuta* larvae may burrow themselves through the fruit of the plant leaving open cavities for pathogens to enter. These pathogens can colonize and cause fruit rot. The damage caused by *Tuta absoluta* leaves farmers with fruit unsuitable for market thus a major loss in their tomato yield.

2.3 Current Control Methods

Chemical pesticides are used in agricultural production to protect a farmer's yield and quality of crops (Atreya, Johnsen & Sitaula, 2012). If farmers follow instructions and recommendations for each chemical pesticide, the farmers can reap the benefits of those pesticides. Farmers can control for vector-disease and protect crops from further damage from pests (Aktar, Sengupta & Chowdhury, 2009). These actions result in improvements in productivity and the quality of the crops, although the chemicals are costly. Unfortunately, some chemical pesticides pose potential risks (Forget, 1993). These include human and environmental health risks. Human health can be affected by chemical pesticides through contact with the pesticides themselves or through residues on food commodities (Aktar et al., 2009). Many different health conditions arise due to direct and indirect contact with chemical pesticides.

Contamination from chemical pesticides can also cause havoc on the surrounding environment including: surface water, ground water, soil, air, and non-target organisms. If non-

target organisms, such as plants, animals, or insects, were to come in contact with an excess amount of chemical pesticides through means of air, water, or soil, they all could be at risk for serious health conditions. These environmental risks can also spread to become additional human health risks through water and air contamination. Many of these risks are mitigated through proper use and protection equipment use by farmers, but these risks increase in developing countries as training and protective wear is not relatively available (Forget, 1993).

In recent years, Nepal has seen an increase in chemical pesticide imports (Atreya et al., 2012). Since the early 2000's pesticide use in the cultivation of vegetable crops in Nepal has also seen a dramatic increase (Maharjan, Aryal, Mainali, Bista, Manandhar, Giri, & Paneru, 2004; Jha and Regmi, 2009). In addition, a recent study in Nepal has shown a lack of training surrounding proper pesticide application and a lack of awareness of the dangers of pesticides (Shrestha, Koirala, & Tamrakar, 2010). The majority of vegetable farms had not received any formal training on chemical pesticide use. In addition, approximately one-third do not read the labels nor does one-half use protective wear during applications. An increase in chemical pesticide use on vegetable farming and a lack of awareness and training propose dangerous implications for vegetable farmers and their surrounding communities in Nepal.

2.4 Integrated Pest Management

With the lead of the Integrated Pest Management Innovation Lab (IPM IL) located at Virginia Tech, iDE Nepal collaborated with professionals across many disciplines to aid in the attempt to reduce chemical pesticides in vegetable production in Nepal, while still controlling pests. iDE Nepal is a non-governmental organization focused on implementing new ideas and technologies to improve Nepal's poor population. The IPM IL is a part of the Feed the Future initiative funded by the United States Government. A sub-project was created to aid the creation

of integrated pest management (IPM) for a variety of vegetable crops in Southern Asia. In light of the approaching *Tuta* migration, part of that sub-project was dedicated to creating an IPM package, specifically for *Tuta* prevention, for Nepalese tomato farmers.

Integrated pest management is an agricultural management approach that combines different agricultural practices to control for agricultural pests while also reducing the need for chemical pesticides (Food and Agriculture Organization, 2019). IPM systems were first introduced to the developed world around 1960 due to the increased presence of environmental damages caused by synthetic chemical pesticides (Harris, 2001; Peshin, Jayaratne & Sharma, 2014). While IPM systems were promoted in developed countries due to this observation, chemical pesticides were being promoted as the only form of pest control within developing countries, particularly Southern Asia (Peshin, Jayaratne & Sharma, 2014). As the population of agricultural pests began to increase in these developing countries, the need for IPM systems became prevalent.

Previous studies have shown that farms that adopt IPM packages have reduced the number of calendar-based chemical pesticide application while also gaining benefits both economically and environmentally (Cuyno, Norton, Rola, 2001; Pretty & Bharucha, 2015). As previously stated, there are obstacles to IPM adoption within developing countries and those obstacles differ depending on the country. To best understand *Tuta absoluta* IPM adoption in Nepal, we first need to examine the *Tuta absoluta* IPM package.

For this sub-project, two separate packages were created based on the type of tomato production. Open field and polyhouse production are wrapped into one package as pests able to reach tomato fields and all practices are universal to these two types of practices. A separate

package of practices was created for the use of a pest exclusion net which excludes all pests from the tomato field. Some of the practices within the packages are identical while some do differ.

The open field and polyhouse production IPM package includes the following practices:

1. Grow tomato seedlings inside a nylon net or netted nursery. This practice will reduce the likelihood of *Tuta* infesting the tomato seedlings.
2. Destroy previous crop residue after the last harvest, thus destroying any pests residing on previous crops. Farmers can either collect and burn the previous crop residue or bury it in a one-foot-deep pit.
3. Do not grow other host crops around the farm and remove host weeds. This will limit the risk of a *Tuta* infestation on the farm. Other host crops include potatoes, eggplant, pepper, tobacco, and pepino melon. There are also several minor host weeds and crops to exclude from the farm.
4. Destroy eggs, larvae and pupae in the field to be planted. This is a precautionary measure to destroy any present *Tuta* in the field before introducing seedlings and young crops. To do this, farmers apply bio-pesticides through drenching measures or plough the field before transplanting.
5. Check seedlings for *Tuta* before transplanting. Another precautionary measure to remove any current *Tuta* eggs or larvae.
6. Spray a neem based botanical pesticide or bio-pesticide. This can be used in addition to pheromone and/or light traps. Neem oil is a botanical insecticide, derived from the neem tree (Khater, 2012). Neem oil contains azadirachtin, a biologically active constitute, that aids in the disruption of the growth cycle of larval insect; including *Tuta absoluta*.

7. Use pheromone or light traps as a form of mass trapping. This is to be done seven days before the transplantation of tomato crops into the field. Multiple types of pheromone and light traps are available. The light trap can either use a blue LED light bulb with a white container or a white LED light with a blue container (Nepal, 2017b; Tropea Garzia et al.,2012). The pheromone trap can either be a water trap with a pheromone lure or a sticky trap with a pheromone lure. The pheromone is specific to the Tomato Leaf Miner. The light trap attracts both males and females while the pheromone trap attracts only the males (Nepal, 2017b). Both traps limit the occurrence of new generations.
8. Alternative applications of botanical insecticides with biopesticides. Biopesticides are pesticides derived from naturally occurring substances including animals, bacteria, minerals and plants (EPA, 2019). These types of pesticides generally control for and affect the targeted pest. Botanical insecticides are derived from plants and are classified as biopesticides (Isman, 2006).
9. Regular field inspections are crucial for proper management of *Tuta*. New infestations can occur throughout the growing season. Early detection of an infestation allows for ample time to identify and apply the proper and most effective treatment.
10. During those regular field inspections, the farmer should also remove and destroy any infected leaves, shoots and fruits immediately. This limits the likelihood of an infestation multiplying or existing.
11. Use plastic mulch around tomato crops. This practices makes identification of *Tuta* in the soil easier while also reducing pupation in the soil. Plastic mulch also acts as weed control and conserves soil moisture and nutrients (Decoteau, Kasperbauer, Daniels, and Hunt, 1988).

The pest exclusion net production package contains some repeating practices as seen above. Practices numbers 1 through 6 are identical with each package. The follow practices are in addition to the identical practices.

1. Double check greenhouse net for holes. This practice is a precautionary measure to prevent *Tuta* from having access to net houses.
2. Keep traffic flow in the greenhouse low. By limiting the number of visits to the net house, the lower the likelihood of an infestation.
3. Install a tight and secure door. There are two common types of door systems for a net house. One is a single zipper door. This system is cost efficient and ensures no holes near the entrance to the net house. The other is a double door system. This system requires a net house to have one door entering an atrium. Inside that atrium, a trap is placed to catch any entering pests. Then from that atrium, you walk through another door into the net house.

Chapter 3: Methods, Data, and Models

3.1 Conceptual Framework

Adoption of IPM technologies can be partially explained by the diffusion of innovation theory. Rogers (2010) defines the diffusion of innovations as, "a social process in which subjectively perceived information about a new idea is communicated." By further breaking down the definitions of diffusion and innovation, the theory can be better understood. Feder and Umali (1993) defines an innovation as "a technological factor that changes the production function..." In this case, the IPM practices represent the new innovation. Diffusion is described by Thirtle and Ruttan (1986) as "a dynamic, aggregative process, over continuous time." It can also be defined as a social change that is caused by the distribution of a new technology (Rogers, 2010). Putting these two definition together in the context of this project creates a formal definition. The diffusion of innovation theory recognizes that the process of social change due to new IPM adoption can influence the adoption rate of IPM technologies. This process thus results in adoption or non-adoption of the IPM practices.

The choice model in consumer theory can also be used to explain a farmer's decision to adopt IPM practices (Fernadez-Cornejo, 1996). It is assumed that farmers are utility maximizers, profit maximizers and cost minimizers. In order to maximize their expected utility, farmers maximize profits by minimizing production costs. Farmers are also risk averse. While pecuniary costs of inputs can be easily determined, there are other costs farmers need to account for. Labor cost, such as time spent in the field, and opportunity costs, such as growing other crops, need to be taken into account.

As for risk, it all depends on the farmer's own values and opinions. If the farmer values the health of their family and the surrounding environment, they may believe chemical pesticides

pose a higher risk than IPM practices. On the other hand, the farmer may value certainty of the effectiveness of chemical pesticides over IPM practices. Farmers are more likely to choose whichever one of two conditions they value most in order to maximize their utility. They will also have to decide if they believe IPM practices will increase their profits. Farmers will only adopt IPM practices if they believe their production profits will increase thus increasing their overall utility.

3.2 Survey and Data

3.2.1 Survey

Survey construction began in early Spring 2018. The survey was designed using previous examples of household surveys implemented by Virginia Tech on IPM projects in other countries as structural guides. Questions in the survey gathered information on demographics, land assets, memberships, agricultural knowledge sources, tomato production, *Tuta absoluta*, pest management, chemical pesticide use, and additional information on tomato consumption and production. The survey has a total of 149 questions (See Appendix B). Many questions could be skipped depending on the answer to the previous answer. The last section of the survey contained questions designed by an Economic Development Specialist at the Virginia Tech Office of Economic Development for a separate study she was conducting in Nepal.

3.2.2 Sample Design

The process of random sampling began at the district level. Four districts in Nepal were selected based on the presence of *Tuta absoluta* and local community business facilitators. The four districts were Lalitpur, Kaski, Banke, and Surkhet. Once the districts were selected, a list of wards with significant tomato production was created. That list was then narrowed again by the presence of local community business facilitators (CBFs). CBFs help the project by distributing

agricultural inputs, including IPM technologies, throughout a treated village. From that list, one ward with significant tomato production and one with a CBF presence were randomly selected. Once a ward was selected, a list of villages was compiled for each ward with the help of local district personnel and the local voter list. The list of villages was then defined by significant tomato production and CBF presence. Villages without significant tomato production were dropped. From the remaining villages on the list, five villages with a CBF presence and five villages without a CBF presence were randomly selected. Once those 10 villages were selected, household data needed to be collected and updated. With the help of local CBFs, knowledgeable locals, and the village voter list, a list of tomato producing households was created. If less than ten tomato producing households were found in a village, the team reverted back to the village lists and randomly selected another village. If the list provided ten or more tomato producing households, the team proceeded to randomly select ten households from that list. If the primary decision maker of the household was not present at the household, another tomato producing household was randomly selected from the household list.

3.2.3 Data Collection

Four enumerators, who were employed as interns at iDE Nepal and had experience working with farmers and *Tuta absoluta* were selected for this project. The enumerators were trained on the questionnaire from May 23 through May 26, 2018. The pretesting of the questionnaire was conducted on May 25, 2018 in the village of Ranaguan in the Lalitpur district of Nepal. A total of eight farmers were surveyed, two per enumerator. The purpose of this pretesting was to allow the enumerators to become accustom to the questionnaire, determine the average length of the survey, and to determine if there were any changes needed in the questionnaire. Pretesting was supervised by the author and her Faculty Supervisor, an Economic

Development Specialist, and employees from iDE Nepal. After pretesting was completed, the team returned to office and made adjustments as needed.

Once the questionnaire was finalized, primary data collection began using the sample design stated above. One hundred farm-households were surveyed per district in a total of four districts. A total of 401 surveys were completed thus creating a cross-sectional data set.

3.3 Determination of Variables

3.3.1 Dependent Variable Construction for Adoption Model

For the purpose of evaluating the first objective, adoption of IPM practices needs to be evaluated. In previous studies, adoption has been expressed in a variety of ways. The most common construction of adoption is as a binary or multinomial variable. Doss and Morris (2000) utilize a two-stage probit model and therefore conceive adoption as a binary variable. Other studies have created a multinomial adoption variable depending on the degree of adoption. Jackson (2017) created a three tiered adoption variable where zero represented farmers who did not adopt, one represented farmers who adopted one practice, and two represented farmers who adopted at least two practices. Travis (2015) created a four level adoption variable in which practices were divided into four categories; simple practices, complex practices, practices with purchased required and practices with no purchase required.

We examined the descriptive statistics of IPM adoption to determine the best construction of the adoption variable for this study. First, the use of net house IPM practices versus open field/polyhouse IPM practices was considered. From the 401 surveys conducted, only one household produced tomatoes within a net house. For this reason, this household was dropped and the study exclusively focuses on open field and polyhouse production.

Reviewing the remaining 400 surveys, only twenty-one producers (5.25%) did not adopt at least one practice. This is shown in in Table 3.1. Because of this finding, a simple binary dependent variable of non-adopters and adopters is not optimal due to the lack of variability. Due to the high adoption of at least one practice, the next step was to examine the descriptive statistics of the data to assess the adoption of simple practices. Those practices that could be understood and sustained without the need of additional knowledge or tools were deemed simple. All remaining practices that required additional knowledge or tools were deemed complex. Table 3.1 shows the descriptive statistics of the two levels. Based on this information, a binary variable was created. Zero represents a non-adopter or simple adopter. Non-adopters (5.25%) did not adopt any IPM practices. Simple adopters (16.25%) adopted at least one simple IPM practice. The two were merged due to the low number of non-adopters. One represents complex adopters. Complex adopters (78.5%) adopted at least one complex practice. This practice could be one standalone complex practice or in addition to any simplistic practices adopted.

Table 3.1: IPM Practices for Polyhouse and Open Field Production

IPM Practice	**Number of Household Responses**
No Adoption	
No IPM practices were adopted	21 (5.25%)
Low Adoption Practices	
Destroy previous crop residue after the last harvest	288 (72.0%)
Do not grow other host crops and remove host weeds	94 (23.5%)
Check seedlings for *Tuta absoluta* before transplanting	37 (9.25%)
Regular field inspections to look for infestations	345 (86.25%)
Remove and destroy infected leaves, shoots and fruits	360 (90.0%)
Complex Adoption Practices	
Grow tomato seedlings inside a nylon net	74 (18.5%)
Apply bio-pesticide in soil as a drenching	47 (11.75%)

Plastic mulch to help identify and reduce pupation	10 (2.5%)
Mass trapping with pheromone and light traps	150 (37.5%)
Spray a bio-pesticide	206 (51.5%)
Alternate applications of botanical pesticides with bio-pesticides	109 (27.25%)

Other options to construct the adoption variable include creating a continuous variable counting all practices, a continuous variable counting all complex practices, or creating a multinomial variable where zero represents non-adopters and simple adopters, one represents medium adopters and two represents high adopters. In the multinomial variable, the complex adopters are spilt into two groups. Medium adopters (28.50%) had adopted at least one complex practice. This could be one standalone complex practice or in addition to any simplistic practices. High adopters (50.00%) had adopted at least two complex practices. Again, this could be two standalone complex practices or in addition to any simplistic practices. While the binary adoption variable will be primarily used in this study, results for alternative adoption variables are also presented.

Table 3.2: IPM Adoption for Multinomial Variable

IPM Adoption Level	**Number of Household Responses**
No Adoption	21 (5.25%)
Low Adoption	65 (16.25%)
Medium Adoption	114 (28.50%)
High Adoption	200 (50.00%)

3.3.2 Selection of Explanatory Variables for Adoption Model

The selection of the explanatory variables for the adoption model were based on social, economic, institutional, and management factors related to Nepali culture and their agricultural

system. Previous studies have used similar groups of explanatory variables with a few adaptations based on their location of study. Below, each explanatory variable is defined with an explanation of its purpose in this study.

1 Age

Age is a continuous variable related to the age of the primary decision maker. Many studies on IPM adoption have shown that age negatively affects IPM adoption (Ghimire and Kafle, 2014; Kabir & Rainnis, 2014; Mugisha, Ogwal-p, Ekere, & Ekiyar, 2004). We expect that the likelihood of adoption of IPM practices will decrease as the age of the farmer increases. The reasoning is that younger primary decision makers are more likely to be risk takers and thus they will be more likely to adopt new farming practices and invest in the future of their farm. This variable is represented in the adoption model by age.

2 Female

Female is a binary variable related to the gender of the primary decision maker. In this case, zero represents a male farmer as the primary decision maker of the household. One represents a female farmer as the primary decision maker. Previous literature has shown gender to have an ambiguous effect on adoption. Doss and Morris's (2000) study on gender effects on adoption of new agricultural technologies in Ghana showed both having a female head of household and female farmer to have a negative effect on adoption. A study conducted in Bangladesh found being a male farmer has a negative effect on adoption of complex practices (Ricker-Gilbert, Norton, Alwang, Miah & Feder, 2008). We expect being female to have a negative effect on IPM adoption. Atreya (2007) showed women farmers in Nepal are less educated on safety and awareness of pesticide use than male farmers. Therefore, we expect female primary decision

makers in Nepal to use chemical pesticide as a primary method to control for Tuta absoluta rather than adopt IPM practices because of their lack of knowledge and awareness. This variable is represented in the adoption model by $female$.

3 Education

Education is a continuous variable related to the number of years of education the primary decision maker received. If the primary decision maker received a type of training, the education variable is represented as one year of education. An increase in the years of education is expected to increase the likelihood of IPM adoption. The reasoning for this is the more educated a farmer is, the more likely they understand and are aware of the negative effects of chemical pesticides. They may be more willing to invest time in educating themselves on IPM practices; thus, becoming more likely to adopt those practices. Previous studies have shown education to have a positive effect on IPM adoption (Mugisha, Ogwal-p, Ekere, & Ekiyar, 2004; Ghimire and Kafle, 2014). This variable is represented in the adoption model by $educ$.

4 Experience Tomato Farming

Experience is a continuous variable related to the number of years the primary decision maker has in tomato farming. Experience is expected to have a negative effect on IPM adoption with the reasoning that farmers with more experience are less likely to be a risk taker and adopt new farming practices. Previous studies have shown experience to have a negative effect on IPM adoption (Ghimire and Kafle, 2014). This variable is represented in the adoption model by $exper$.

5 Migrant in Household

Migrant is a binary variable related to the presence of a migrant in the farm household. In Nepal, it is common for male members of a household to migrate to surrounding countries for work. Zero represents no migrants were present in the household. One represents at least one migrant was present in the household. The expected sign for migrant is ambiguous. As household members migrate, they are decreasing the household income for the time being therefore current household members may adopt IPM practices as a method to decrease initial input costs. This would cause migrant to have a positive relationship between migrant and adopt. On the other hand, migrant may have a negative relationship with adopt if the household becomes more risk adverse when migrants leave for work as the household income is limited until migrants return. This variable is represented in the adoption model by $migrant$.

6 Farm Size

Farm size serves as the proxy variable for wealth. Farm size is a continuous variable related to the number of ropani of land owned by the primary decision maker. Previous studies have shown farm size to be ambiguous. Kabir and Rainis (2015) show wealth had a negative effect on the adoption but annual income had a positive effect on adoption of IPM practices. Increased wealth may cause a positive relationship with adoption if households are more risk taking as wealth increases thus more willing to try new IPM practices on their farms. Ghimire and Kafle's (2014) study in Nepal showed farm size to have a negative relationship with adoption. Other studies have shown household income to have a significantly negative effect on adoption (Mugisha, Ogwal-p, Ekere, & Ekiyar, 2001). Increased wealth may have a negative relationship with adopt if increased wealth of a household decreases the household concern of the price of the chemical pesticides. This variable is represented in the adoption model by $fmsz$.

7 Household Labor

Household labor is a continuous variable related to the number of members in the household who are able to work. Mugisha, Ogwal-p, Ekere, & Ekiyar's study shows household size to have significantly negative effect on IPM adoption (2004). Reasoning for this could be as household size increased, the household cost of living increased. To protect their crop and avoid risk, they would choose not to adopt the new technologies. Other studies, including one conducted by Hasan (2007), found household labor to have a positive effect on IPM adoption. Research has shown IPM to be more labor-intensive than the chemical pesticides (Jørs et al., 2017). From previous studies, we can expect an increase in household labor to have an ambiguous effect on IPM adoption. This variable is represented in the adoption model by $houselab$.

8 Land Dedicated to Tomatoes

Land dedicated to tomatoes is a continuous variable related to the number of ropani of land owned by the primary decision maker that is dedicated for tomatoes. The amount of land dedicated to tomato production is expected to have a positive effect on IPM adoption. As land under tomato cultivation increases, farmers may become more concerned with the quantity and quality of their tomato yields as income from tomato production becomes a larger portion of the household income. Adoption of IPM practices would allow farmers to sustainably grow their tomatoes without the risk of chemical residue on their crop. Kabir and Rainis (2014) found land under vegetable cultivation to have a positive effect on the adoption of IPM practices in Bangladesh. This variable is represented in the adoption model by $landt$.

9 Distance to Extension Office

Distance to agricultural extension office is a continuous variable measured in kilometers. Distance to the closest extension office is expected to have a negative effect on IPM adoption.

This may be due to the availability of extension offices and their advice. The closer a farmer is to the extension office, the more likely they are to come in contact with the extension office that is promoting IPM adoption. This variable is represented in the adoption model by $distag$.

10 Member of an Organization

Member is a binary variable related to the membership status of the primary decision maker. This membership status can be to any farm or community organization including savings groups, marketing cooperatives and/or marketing groups/collection centers. Being a member of an organization is expected to have a positive effect on IPM adoption as education on chemical pesticides and IPM can be discussed within the group. Several studies have shown a significantly positive relationship between membership and adoption (Ghimire & Kafle, 2014; Mugisha, Ogwal-p, Ekere, & Ekiyar, 2004). This variable is represented in the adoption model by $memb$.

11 Community Business Facilitator

Community Business Facilitator (CBF) is a binary variable related to the presence of a CBF in the village of the primary decision maker. Zero represents a non-CBF village while one represents a CBF village. iDE Nepal implemented CBFs in input-needing villages throughout Nepal. CBFs distribute agricultural inputs throughout a village to aid in the improvement of their agricultural productions. These CBFs are generally female residents of the village who have knowledge and experience with agricultural technologies and ability to travel to input suppliers. CBF presence is expected to have a positive relationship with IPM adoption because they were created by the institute that implements IPM technologies throughout Nepal. This variable is represented in the adoption model by cbf.

12 Advice Received from Media Outlets

Advice received from media outlets is a binary variable related to if the primary decision maker received advice from media outlets. These outlets include radio, television/video, newspaper/leaflet, mobile phone messages, social media, or agricultural mobile applications on a smart phone. Jackson (2017) found media to have a positive relationship with adoption of IPM with rice farmers in Cambodia. For this study, we expect media to have an ambiguous relationship with adoption due to the variability in information shared on through media outlets. This variable is represented in the adoption model by $media$.

13 Advice Received from Agricultural Outlets

Advice received from agricultural outlets is a binary variable related to if the primary decision maker received advice from agricultural outlets. These outlets include agricultural extension workers, community business facilitators, an NGO agricultural extension worker, field day, farmer field school, or farmers' group. This variable does not include advice received from chemical pesticide input suppliers. Many studies have found a positive relationship between extension contact and IPM adoption (Kabir and Rainis, 2014; Mugisha, Ogwal-o, Ekere, Ekiyar, 2004). We expect these outlets to educate farmers on new agricultural technologies such as IPM. If primary decision makers are to receive advice from one or more of these outlets, we expect the primary decision makers to be more likely to adopt IPM practices. This variable is represented in the adoption model by $agcon$.

14 Advice Received from Personal Connections

Advice received from personal connections is a binary variable related to if the primary decision maker received advice from personal outlets. These outlets include relatives, neighbors, friend, or lead farmer. This variable is expected to have an ambiguous relationship with IPM adoption.

Jackson (2017) found personal advice to have a positive relationship with adoption. Though one study showed a positive relationship, for this study, we expect advice received from personal connects to have an ambiguous relationship with IPM adoption due to the variability in outlets. Advice from a lead farmer could be different than that of a relative. This variable is represented in the adoption model by $personal$.

15 IPM Training

IPM training is a binary variable related to if the primary decision maker received IPM training. Previous studies have shown training to have a positive relationship with IPM adoption (Ghimire and Kafle, 2014; Kabir and Rainis, 2015). IPM training provides farmers with the knowledge and tools to implement IPM technologies in their fields. If the primary decision maker attends an IPM training session, we expect to see a positive reaction to IPM adoption. It is expected that omitted variables within the adoption model are correlated with this variable. For that reason, an instrumental variable will be used. Further explanation of this will occur in section 3.4.3. This variable is represented in the adoption model by $train$.

16 *Tuta absoluta* IPM Training

Tuta absoluta IPM training is a binary variable related to if the primary decision maker received IPM training specifically on *Tuta absoluta* prevention. IPM training specifically for *Tuta absoluta* provides farmers with the knowledge and tools to implement technologies from the *Tuta absoluta* IPM package within their tomato fields. If the primary decision maker attends a *Tuta absoluta* IPM training session, we expect to see a positive effect on IPM adoption. It is expected that this variable is endogenous with omitted variables. For that reason, an

instrumental variable will be used. Further explanation of this will occur in sections 3.4.3. This variable is represented in the adoption model by $traintuta$.

17 Severity of *Tuta absoluta*

Severity of *Tuta absoluta* is a binary variable related to the severity of the *Tuta absoluta* in the primary decision maker's farm. The primary decision makers were asked, on a scale of zero to three, how much has *Tuta absoluta* impacted their tomato fields. Zero represented no damage, one represented low (some damage, yield not affected), two represented medium (some damage, yield affected), and three represented high (major damage and effect on yield). From the collected data, a binary variable was created to represent severity having an effect on yield, where zero represents yield not affected and one represents yield affected. We expect severity to have an ambiguous relationship with IPM adoption. When a farmer's yield is affected, we expect them to either resort to adopting IPM practices or applying chemical pesticides. This variable is represented in the adoption model by sev.

A summary of the expected signs for the explanatory variable in the adoption model can be found in Table 3.3.

Table 3.3 Expected Signs of Explanatory Variables for the Adoption Model

Name	**Description**	**Expected Sign**
age	Age	-
female	Gender	-
educ	Education	+
exper	Experience Tomato Farming	-
migrant	Migrant in Household	+/-
fmsz	Farm Size	+/-
houselab	Household Labor	+/-
landt	Land Dedicated to Tomatoes	+
distag	Distance to Extension Office	-

memb	Member of an Organization	+
cbf	Community Business Facilitator	+
media	Advice Received from Media Connections	+/-
agcon	Advice Received from Agricultural Connections	+
personal	Advice Received from Personal Connections	+/-
train	IPM Training	+
traintuta	*Tuta absoluta* IPM Training	+
sev	Severity of *Tuta absoluta*	+/-

3.3.3 Dependent Variable Construction for Pesticide Use Model

For this study, we asked farmers to estimate the amount of expenditures spent on chemical pesticides for control of *Tuta absoluta*. Expenditures are stated in Nepalese rupees. In 2018 the average exchange rate of United States dollars to Nepalese rupees was 109 Nepalese rupees per one US dollar (XE, 2019). For the construction of this model, the dependent variable will be expenditures on chemical pesticides, a continuous variable reflecting the number of Nepalese rupees spent on chemical pesticides to control for *Tuta absoluta*.

3.3.4 Selection of Explanatory Variables for Pesticide Use Model

The selection of variables for the pesticide use model is similar to selection in the adoption model. Previous studies were examined to determine the best selection of explanatory variables.

1 Adoption

Tuta absoluta IPM adoption is a binary variable related to if the households adopted at least one complex IPM practice. Adoption is suspected to have a negative relationship with the number of worker days spent applying pesticides. Chemical pesticides and IPM practices act

as substitutes for one another. If farmers were to adopt IPM practices, they would be more likely to reduce the number of Nepalese rupees on chemical pesticide to control for *Tuta absoluta* in their tomato fields. This variable is represented in the adoption model by $adopt$.

2 Hired Labor

Hired labor is a binary variable related to if the primary decision maker hired labor to spray chemical pesticide on their tomato fields. Hired labor is expected to have a positive relationship with the amount of expenditures spent on chemical pesticides. Zero represents the primary decision maker did not hire any labor to apply chemical pesticides on their tomato fields. One represents the primary decision maker did hire labor to apply chemical pesticides on their tomato fields. This variable is represented in the pesticide use model by $hiredlabor$.

Descriptions of the explanatory variables age, gender, education, experience, farm size, land dedicated to tomato production, CBF, advice from media, advice from agricultural sources, advice from personal sources, and severity can be found in section 3.3.3. The purpose of their placement in the pesticide use model are shown below.

3 Age

The age of the primary decision maker is expected to have a positive relationship with expenditures on pesticides. IPM practices are known to be more labor-intensive so the older the primary decision maker, the less likely they are to adopt labor-intensive practices and remain using chemical pesticides (Jørs et al., 2017).

4 Female

Females are expected to be less aware of the implications and dangers of chemical pesticide use. Therefore, this variable expected to have a positive relationship with pesticide expenditures.

5 Education

Education is expected to have a negative relationship with chemical pesticide expenditures. As education increases, primary decision makers may become more knowledgeable on and aware of the negative effects chemical pesticides have; thus making them more likely to learn about and implement alternative methods for pest control.

6 Experience Tomato Farming

Experience is expected to have a positive relationship on pesticide expenditures. The more experience a farmer has in tomato production, the more likely they are to practices the methods they know and trust. They are less likely to be risk takers as they know what works for their farm.

7 Farm Size

As a proxy variable for wealth, the relationship between farm size and pesticide expenditures is ambiguous. As a farmers' wealth increases, they are may be more risk taking and willing to try new pest control methods such as IPM thus causing farm size to have a negative relationship with expenditures. On the other hand, as a farmers' wealth increases, they may be able to afford to buy a greater amount of pesticides than those farmers who are less wealthy. Therefore, causing farm size to have a positive relationship with pesticide expenditures.

8 Household Labor

Household labor also has an ambiguous relationship with pesticide expenditures. Household labor could have a negative relationship with chemical pesticide expenditures if the primary decision maker is concerned with their household health and health risks associated with improper chemical pesticide use. One the other hand, household labor could have a positive effect on chemical pesticide expenditures if the household is risk avoiding to ensure income and remain the known method of chemical pesticides as their primary pest control method.

9 Land Dedicated to Tomatoes

Land dedicated to tomatoes is expected to have a negative relationship with chemical pesticide expenditures. As land under tomato cultivation increases, farmers become more concerned with the quantity and quality of their production as income from tomato production becomes a larger percentage of the total household's income. Therefore, as land dedicated to tomatoes increases, farmers are more willing to look for alternative pest control methods to increase the quality of their tomato yields.

10 Community Business Facilitator

CBF presence is expected to have a negative relationship with pesticide expenditures. The purpose of a CBF is to supply agricultural inputs, specifically IPM technologies, to farmers within a village. CBFs were implemented by the same contributors who implemented IPM practices throughout Nepal. Therefore, we expect CBFs to spread IPM technologies thus reducing the need for additional chemical pesticide expenditures.

11 Advice Received from Media Outlets

Advice received from media outlets is expected to have an ambiguous relationship to pesticide expenditures. Due to the possible variability in information shared through media sources, we cannot be sure of the type of information shared from media sources. Depending

on the original sources of information, the content could either encourage or discourage the number of expenditures spent on chemical pesticides.

12 Advice Received from Agricultural Outlets

Advice received from agricultural outlets is expected to have a negative relationship to pesticide expenditures. We expect the sources of agricultural advice to be promoting the adoption of new agricultural technologies as the outlets of information aim to improve agricultural development in Nepal.

13 Advice Received from Personal Connections

Advice received from personal connections is expected to have an ambiguous relationship to pesticide expenditures. Due to the variability in outlets of personal advice, we cannot be confident personal sources of information either encourage or discourage pesticide use.

14 Severity of *Tuta absoluta*

We expect severity to have an ambiguous relationship with the amount of expenditures spent on chemical pesticides to control for *Tuta absoluta*. When a farmer's yield is affected, they can either resort to applying chemical pesticides or adopting IPM practices.

Table 3.4 Expected Signs of Explanatory Variables for the Pesticide Model

Name	**Description**	**Expected Sign**
adopt	IPM Adoption	-
age	Age	+
female	Gender	-
educ	Education	-
exper	Experience Tomato Farming	+
fmsz	Farm Size	+/-
houselab	Household Labor	+/-
landt	Land Dedicated to Tomatoes	-
cbf	Community Business Facilitator	-

media	Advice Received from Media Connections	+/-
agcon	Advice Received from Agricultural Connections	-
personal	Advice Received from Personal Connections	+/-
hiredlabor	Labor was hired to apply chemical pesticides	+
sev	Severity of *Tuta absoluta*	+/-

3.4 Econometric Models for Adoption Model

3.4.1 Adoption Model Construction

For this study, adoption is a binary variable where zero represents non-adopters and adopters of simple practices and one represents adopters of complex practices. The linear probability model could have been used as it is generally straight forward and simple to comprehend. If we used this type of model with the binary dependent variable, we would have run into two limitations: the partial effects of the explanatory variables would be constant and the fitted probabilities could surpass the limit between zero and one (Wooldridge, 2013). Because of these limitations, other possible models were examined. Due to the binary dependent variable, we focused on binary response models.

In a binary response model, the response probability,

(1) $$P(y = 1|x) = P(y = 1|x_1, x_2, \dots, x_k),$$

shows the probability of the binary dependent variable response conditioned on independent variables. In this equation, x represents all explanatory variables in the model. As the binary dependent variable needs to be a value of zero and one, it cannot be assumed that the response

probability is linear (Woodbridge, 2013). Therefore, a binary response model needs to be defined as:

$$P(y = 1|x) = G(\beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k), \quad (2)$$

where G is a function that only allows values to have a range between zero and one (Wooldridge, 2013). This model explains the impacts of the independent variables, x_i, on the response probability (Wooldridge, 2013).

We could have used ordinary least squares (OLS) to estimate a linear probability model, but decide against it because results have a possibility of being biased and inconsistent because of the nonlinear nature of the model (Horrace & Oaxaca, 2006). Using OLS would cause us to worry about the predictions being outside a zero-one interval and the presence of heteroskedasticity. In order to avoid this issue, maximum likelihood estimation (MLE) can be used. Maximum likelihood estimation is consistent, asymptotically normal, and asymptotically efficient under general conditions (Wooldridge, 2013). Heteroskedasticity in var(y|x) is resolved because MLE is based on the density of y given x (Wooldridge, 2013).

Two popular nonlinear functions used in previous agricultural technology adoption studies are logit and probit models. In a logit model, G is the logistic function whereas G in the probit model is the standard normal cumulative distribution function (Woodridge, 2013). Mugisha et al. (2004) used a probit model to find the determinates of IPM practices in groundnut production. Doss and Morris (2000) approached their research on adoption of fertilizers and modern varieties of maize in Ghana with a probit model. Ghimire and Kafle's (2014) research regarding adoption of apple IPM practices in Nepal used a probit model to determine the factors influencing IPM adoption. Jackson (2017) used a multinomial logit model to assess the

determinants of IPM practices of Cambodian rice farmers. Hasan (2017) utilized an ordered probit model to determine the factors affecting IPM adoption of Kenyan vegetable farmers.

A probit model was determined to best serve this study. For the probit model, the G in the response model is the standard cumulative distribution function, ensuring the binary response model is limited to the range between zero and one for all parameters (Wooldridge, 2013). It is expressed as an integral,

(3) $$G(z) = \Phi(\mathrm{z}) \equiv \int_{-\infty}^{z} \phi(\mathrm{v})\mathrm{dv}$$

(Wooldridge, 2013).

The $\Phi(\mathrm{z})$, is the standard normal density expressed as:

(4) $$\Phi(\mathrm{z}) = (2\pi)^{-\frac{1}{2}}\exp(-z^2/2)$$

(Wooldridge, 2013).

The probit model and response probability can be derived from a latent variable model (5) shown as:

(5) $y^* = \beta_0 + x\beta + e, \quad y = 1[y^* > 0]$

where $y = 1[y^* > 0]$, the indicator function, takes a value of one or zero depending on the sign of y^* (Wooldridge, 2013). For the probit model, e is assumed to be normally distributed.

With a binary response model, the objective is to understand the effect of certain variables, x, on the response probability (Wooldridge, 2013). To do this, marginal effects must be calculated. Both continuous and binary explanatory variables require separate equations to calculate the partial effects. For continuous variables, the following equation is calculated:

(6) $\frac{\partial p(x)}{\partial x_j} = g(\beta_0 + x\beta)\beta_j, \ \ where\ g(z) = \frac{dG}{dz}(z)$

(Wooldridge, 2013). For binary variables, partial effects can be calculated by:

(7) $G(\beta_0 + \beta_1 + \beta_2 x_2 + \cdots + \beta_k x_k) - G(\beta_0 + \beta_2 x_2 + \cdots + \beta_k x_k)$

(Wooldridge, 2013).

3.4.2 Structural Equation of Adoption Model

The structural equation for the adoption model is expressed as:

(5) $P(adopt = 1|x) = G(\beta_0 + \beta_1 age + \beta_2 female + \beta_3 educ + \beta_4 exper + \beta_5 migrant + \beta_6 fmsz + \beta_7 houselab + \beta_8 landt + \beta_9 distag + \beta_{10} memb + \beta_{11} cbf + \beta_{12} media + \beta_{13} agcon + \beta_{14} personal + \beta_{15} train + \beta_{16} traintuta + \beta_{17} sev + \varepsilon)$

where $adopt$ is the a discrete dependent variable representing the intensity of adoption ranging from zero to one, the function $G(\cdot)$ is represented by equation (3), β_0 represents the intercept, β_1 through β_{17} represent the coefficients of the explanatory variables, $age,\ female,\ educ,\ exper, migrant,\ fmsz,\ houselab,\ landt,\ distag,\ memb,\ cbf,\ media,\ agcon,\ personal,\ train,\ traintuta$ and $tutapres$, and ε represents the error term.

Table 3.5: Description of Adoption Model Variables

Name	Variable	Description	Type	Description of Values/Units	Mean (SD)
adopt	Adoption of IPM practices	If primary decision maker has adopted a complex IPM practice to control for *Tuta absoluta*	Discrete	0=Non/simple adopters 1=Adopt at least one complex IPM practice	0.785 (0.411)
age	Age	Age of the primary decision maker	Continuous	years	42.36 (12.05)

female	Gender	Gender of primary decision makers	Discrete	0=Male, 1=Female	0.708 (0.455)
educ	Education	Years of education the primary decision maker has received	Continuous	years	5.213 (4.49)
exper	Experience	Years of experience the primary decision maker has in tomato cultivation	Continuous	years	6.455 (4.34)
migrant	Migrant	If any family member has migrated to another region or country for work	Discrete	0=No, 1=Yes	0.293 (0.455)
fmsz	Farm size	Farm size in ropani	Continuous	ropani	8.30 (7.07)
houselab	Household labor	Number of workers in the household	Continuous	workers	4.11 (1.998)
landt	Land in tomato production	Size of the plot of land on the farm dedicated to tomato production in ropani	Continuous	ropani	1.01 (1.85)
distag	Distance to agricultural extension office	Distance to nearest agricultural extension office in kilometers	Continuous	kilometers	8.78 (5.23)
memb	Membership	If the primary decision maker is a member of any farm or community organization	Discrete	0=No, 1=Yes	0.935 (0.247)
CBF	Community Business Facilitator (CBF)	Household is located in a village with a CBF present	Discrete	0=No, 1=Yes	0.498 (0.501)
media	Media source	Primary decision maker has received agricultural knowledge from at least one of the following source: radio, television or video, newspaper/leaflet, mobile phone messages, social media, or agricultural mobile applications	Discrete	0=No, 1=Yes	0.82 (0.385)
agcon	Agricultural source	Primary decision maker has received	Discrete	0=No, 1=Yes	0.875 (0.331)

		agricultural knowledge from at least one of the following sources: a government agricultural extension worker, CBF, an NGO agricultural extension agent, farmer field school, or field day			
personal	Personal source	Primary decision maker has received agricultural knowledge from at least one of the following sources: relatives, neighbor, friends, or lead farmer	Discrete	0=No, 1=Yes	0.9425 (0.233)
train	IPM training	Primary decision maker has received IPM training	Discrete	0=No, 1=Yes	0.61 (0.488)
traintuta	*Tuta absoluta* IPM training	Primary decision maker has received IPM training specifically for *Tuta absoluta*	Discrete	0=No, 1=Yes	0.1975 (0.399)
sev	Severity of *Tuta absoluta*	*Tuta absoluta* has affected the household's tomato yield	Discrete	0= yield not affected, 1= yield affected	0.76 (0.428)

3.4.3 Endogeneity of Adoption Model

Potential endogeneity issues were suspected in the adoption model. An endogeneity issue within a model could cause the estimators to become biased and inconsistent (Wooldridge, 2013). An endogeneity issue arises when one or more explanatory variables are suspected to be correlated with unobserved variables, otherwise known as the error term, ε. This can be represented by the following equation:

(1) $$cov(x, \varepsilon) \neq 0$$

where x represents the endogenous explanatory variables. To address this issue, we created an instrumental variable (IV) for each of the suspected endogenous variables. An instrumental variable, represented by z in the following equations, is a variable that has no effect on the dependent variable, y, ceteris paribus. It is also uncorrelated with the omitted variables (2) and is correlated with the endogenous explanatory variables (3), x. This can also be expressed as instrument exogeneity or instrument relevance. These requirements are represented by the equations below:

(2) $$cov(z, \varepsilon) = 0$$

(3) $$cov(z, x) \neq 0$$

(Wooldridge, 2013). Along with the requirements listed above, instrumental variables must also be strong. The strength of an IV is determined by the degree of correlation between the IV and endogenous variable. Weak instruments, those with a weak correlation to x, can cause asymptotic bias (Wooldridge, 2013).

Within the adoption model, we had two suspected endogenous variables: $train$ and $traintuta$. Primary decision makers have the individual choice to attend or not attend either a IPM training or *Tuta absoluta* specific IPM training. We suspect there are unobserved variables influencing these individual decisions. For each suspected endogenous variable we needed to test for endogeneity. To test for endogeneity, a model for each suspected endogenous variable was created so residuals could be obtained. Those residuals were then inserted into the structural equation of the adoption model. Since the adoption model contained two suspected endogenous models, residuals from both equations are tested for joint significance (Wooldridge, 2013).

IPM Training

The first variable we suspected to be endogenous was IPM training ($train$). IPM training is a binary variable for whether a primary decision maker received any kind of training related to IPM. Primary decision makers may voluntarily attend IPM trainings because of other unobserved variables such as density of primary decision makers in their village attending IPM trainings. This density was not observed within the adoption model and was correlated with the IPM training variable. Again, the suspected endogeneity needed to be examined so accurate estimates of the determinates of IPM adoption in the adoption model could be observed.

We created a model to predict IPM training participation. Again, $train$ is a binary variable so a probit model will be used.

$$P(train = 1|x) = G(\beta_0 + \beta_1 villtrain + \beta_2 age + \beta_3 female + \beta_4 educ + \beta_5 exper + \beta_6 migrant + \beta_7 fmsz + \beta_8 houselab + \beta_9 landt + \beta_{10} distag + \beta_{11} memb + \beta_{12} media + \beta_{13} agcon + \beta_{14} personal + \beta_{15} traintuta + \beta_{16} sev + \beta_{17} villtrain + \varepsilon)$$

Where all explanatory variables affect the probability of IPM training participation. These variables with the exception of $villtrain$ are the same variables represented in the adoption model. $villtrain$ is a continuous variable of the density of primary decision makers in a village who attended a training related to IPM. This variable acts as an instrumental variable for $train$. This number was calculated by summing the number of primary decision makers who attended an IPM training and dividing that number by the total number of primary decision makers in the village. The reasoning behind the construction of this instrumental variable was the more popular

IPM training is in a village, the more likely a primary decision maker is to attend an IPM training themselves. All primary decision makers in each village received the same value for this variable. Endogeneity and IV strength testing was conducted in STATA using the command *estat endog* and *estat firststage*.

Tuta absoluta IPM Training

The second explanatory variable we suspected to be endogenous was *Tuta absoluta* IPM training ($traintuta$). *Tuta absoluta* IPM training is a binary variable for whether a primary decision maker received IPM training to manage *Tuta absoluta*. Primary decision makers may voluntarily attend IPM trainings relating to *Tuta absoluta* because of other unobserved variables such as density of primary decision makers in their village attending *Tuta absoluta* IPM trainings. This density was not observed within the adoption model and was correlated with the *Tuta absoluta* IPM training variable. Again, this suspected endogeneity needed to be examined so accurate estimates of the determinates of IPM adoption in the adoption model could be observed.

We created a model to predict *Tuta absoluta* IPM training participation. Again, $traintuta$ is a binary variable so a probit model will be used.

(6) $P(traintuta = 1|x) = G(\beta_0 + \beta_1 villtraintuta + \beta_2 age + \beta_3 female + \beta_4 educ + \beta_5 exper + \beta_6 migrant + \beta_7 fmsz + \beta_8 houselab + \beta_9 landt + \beta_{10} distag + \beta_{11} memb + \beta_{12} media + \beta_{13} agcon + \beta_{14} personal + \beta_{15} train + \beta_{16} sev + \beta_{17} villtraintuta + \varepsilon)$

Where all explanatory variables affect the probability of *Tuta absoluta* IPM training participation. These variables with the exception of $villtraintuta$ are the same variables represented in the adoption model. $villtraintuta$ is a continuous variable of the density of

primary decision makers in a village who attended a training related to IPM of *Tuta absoluta*. This variable acts as an instrumental variable for $traintuta$. This number was calculated by summing the number of primary decision makers who attended a *Tuta absoluta* specific IPM training and dividing that number by the total number of primary decision makers in the village. The reasoning behind the construction of this instrumental variable was the more popular *Tuta absoluta* IPM training is in a village, the more likely a primary decision maker is to attend a *Tuta absoluta* IPM training themselves.

Results from these tests showed $train$ and $traintuta$ were endogenous and the selected instrumental variables were strong. For this reason, an instrumental variable regression is needed. The STATA command *eprobit* was used. Unlike *ivprobit*, *eprobit* accommodates for binary endogenous covariates (StataCorp, 2019).

3.5 Econometric Models for Pesticide Use Model

3.5.1 Pesticide Use Model Construction

For the second objective, we compared the amount of expenditures spent on chemical pesticides for control of *Tuta absoluta* between tomato farmers who adopted complex *Tuta absoluta* IPM practices and those farmers who adopted low or no IPM practices. Looking back on chapter two, we examined the definition and objective of IPM practices. One of those objectives was to reduce the need of chemical pesticides on tomato production. Hopes of the project were to fully eliminate the need for chemical pesticide applications and to only utilize them as a last resort. For the second objective of this paper, we examined the determinates of chemical pesticide expenditures to control for *Tuta absoluta* particularly focusing on how IPM adoption affects the amount of expenditures spent on chemical pesticides.

Previous studies regarding chemical pesticide use in an IPM setting have used both ordinary least square (OLS) and two-stage least squares (2SLS) (Jackson, 2017; Hasan, 2017). Both estimators require a continuous dependent variable, which we also observed in this study. This difference between the two estimators is the use of instrumental variables (Wooldridge, 2013). Similar to the adoption model, we expected the pesticide use model to contain at least one endogenous variable because of the possibility of unobserved variables to affect the endogenous variable. Before we confirmed a model, the suspected endogeneity needed to be examined so accurate estimates of the determinates of chemical pesticide use could be observed.

3.5.2 Structural Equation of Pesticide Use Model

The structural equation of the pesticide use model can be represented as:

$$(1)\ workdays = \beta_0 + \beta_1 adopt + \beta_2 age + \beta_3 female + \beta_4 educ + \beta_5 exper + \beta_6 fmsz + \beta_7 houselab + \beta_8 landt + \beta_9 cbf + \beta_{10} media + \beta_{11} agcon + \beta_{12} personal + \beta_{13} hiredlabor + \beta_{14} sev + \varepsilon$$

where $workdays$ is the a continuous dependent variable representing the number of worker days per ropani that the household spent applying chemical pesticides to their tomato fields, β_0 represents the intercept, β_1 through β_{13} represent the coefficients of the explanatory variables, $adopt, age, female, educ, exper, fmsz, houselab, landt, cbf, media, agcon, personal, hiredlabor$ and sev represent each explanatory variables, and ε represents the error term.

Table 3.6: Description of Variables for Pesticide Use Model

Name	Variable	Description	Type	Description of Values/Unit	Mean (SD)
chemcost	Chemical pesticide expenditures	The amount of expenditures spent on chemical pesticides to	Continuous	Nepalese rupees	1271.68 (2339.5)

		control for *Tuta absoluta*			
adopt	Adoption of IPM practices	If the household has adopted a complex IPM practices to control for *Tuta absoluta*	Discrete	0=Non/simple adopters 1=Adopt at least one complex IPM practice	0.785 (0.411)
age	Age	Age of the primary decision maker	Continuous		42.36 (12.05)
female	Gender	Gender of primary decision maker	Discrete	0=Male, 1=Female	0.708 (0.455)
educ	Education	Years of education the primary decision maker has received	Continuous		5.213 (4.49)
exper	Experience	Years of experience the primary decision maker has in tomato cultivation	Continuous		6.455 (4.34)
fmsz	Farm size	Farm size in ropani	Continuous		8.30 (7.07)
houselab	Household labor	Number of workers in the household in ropani	Continuous		4.11 (1.998)
landt	Land in tomato production	Size of the plot of land on the farm dedicated to tomato production	Continuous		1.01 (1.85)
cbf	Community Business Facilitator (CBF)	Household is located in a village with a CBF present	Discrete	0=No, 1=Yes	0.498 (0.501)
media	Media source	Primary decision maker has received agricultural knowledge from at least one of the following source: radio, television or video, newspaper/leaflet, mobile phone messages, social media, or agricultural mobile applications	Discrete	0=No, 1=Yes	0.82 (0.385)
agcon	Agricultural source	Primary decision maker has received agricultural knowledge from at least one of the	Discrete	0=No, 1=Yes	0.875 (0.331)

		following sources: a government agricultural extension worker, CBF, an NGO agricultural extension agent, farmer field school, or field day			
personal	Personal source	Primary decision maker has received agricultural knowledge from at least one of the following sources: relatives, neighbor, friends, or lead farmer	Discrete	0=No, 1=Yes	0.9425 (0.233)
sev	Severity of *Tuta absoluta*	*Tuta absoluta* has affected a household's tomato yield	Discrete	0= yield not affected, 1= yield affected	0.76 (0.428)

3.5.3 Endogeneity

For the pesticide model, we suspected one of the explanatory variables, $adopt$, to cause an endogeneity issue. We used similar methods expressed in the adoption model to determine if it did cause an endogeneity issue.

IPM Adoption

The explanatory variable we suspected to be endogenous in the pesticide model is *Tuta absoluta* IPM adoption ($adopt$). *Tuta absoluta* IPM adoption is a binary variable for whether a primary decision maker adopted at least one complex IPM practice relating to *Tuta absoluta.* Primary decision makers may voluntarily choose to adopt any amount of complex practices. This decision may be influenced by unobserved variables not included in the adopt model such as distance to agricultural extension and IPM training. This suspected endogeneity needed to be examined so accurate estimates of the determinants of pesticide use could be observed. To test for an endogeneity issue in a linear regression model, we compared both OLS and 2SLS

estimates to determine if they are statistically significant. Wooldridge states if the estimates are consistent with one another, all explanatory variables can be considered exogenous (2013).

To begin testing, we needed a model to predict *Tuta absoluta* IPM adoption. This equation is identical to the adoption model stated in section 3.4.2.

(6) $P(adopt = 1|x) = G(\beta_0 + \beta_1 age + \beta_2 female + \beta_3 educ + \beta_4 exper + \beta_5 migrant + \beta_6 fmsz + \beta_7 houselab + \beta_8 landt + \beta_9 distag + \beta_{10} memb + \beta_{11} cbf + \beta_{12} media + \beta_{13} agcon + \beta_{14} personal + \beta_{15} train + \beta_{16} traintuta + \beta_{17} sev + \varepsilon)$

Where all explanatory variables affect the probability of *Tuta absoluta* IPM adoption including the instrumental variables, $distag$ and $traintuta$. This model was then regressed and residuals were obtained. Those residuals were then added to the structural equation and tested using OLS. Endogeneity is confirmed if the residuals from the first equation are statistically significant from zero (Wooldridge, 2013). The results from this test showed $adopt$ to be endogenous and the selected instrumental variables were strong. Therefore, 2SLS estimation was used for this model. This was conducted in STATA using the command iv*regress 2sls*.

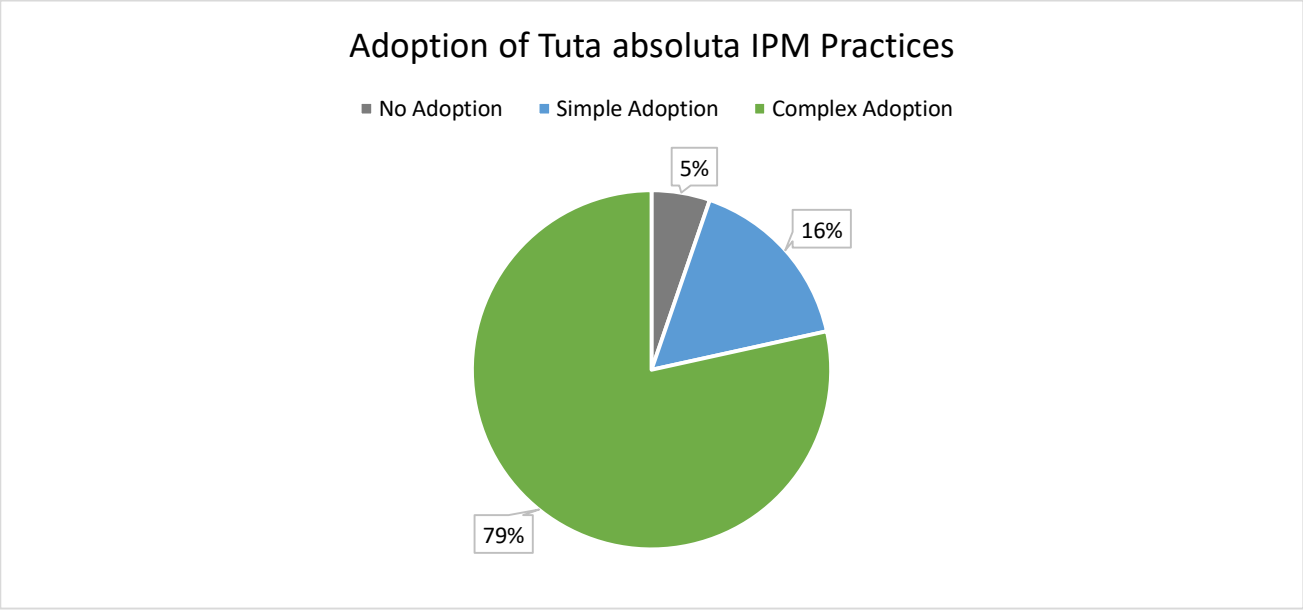
Chapter 4: Results and Discussion

4.1 Objective 1: Determinants of *Tuta absoluta* IPM Adoption

4.1.1 Extent of Adoption

Four-hundred and one households were surveyed during data collection. Of those households, only one produced tomatoes in a greenhouse/net house setting. This household was dropped. With the remaining four-hundred households, we examine the extent of adoption. Non-adopters included households that did not use any *Tuta absoluta*-specific IPM practices to control for *Tuta absoluta* in their tomato fields. Simple adopters only include households that adopted at least one simple *Tuta absoluta*-specific IPM practice and no complex *Tuta absoluta*-specific IPM practices to control for *Tuta absoluta* in their tomato fields. Complex adopters included households that used any amount of complex *Tuta absoluta* specific IPM practices to control for *Tuta absoluta* in their tomato fields. A description of simple and complex practices can be found on Table 3.1 in section 3.3.1. Figure 4.1 below shows 21 (5%) of households are non-adopters, 65 (16%) are simple adopters, and 314 (79%) are complex adopters.

Figure 4.1: Adoption of *Tuta absoluta* IPM Practices



We can further examine the extent of adoption for each *Tuta absoluta* IPM practice. Figure 4.2 shows the portion of the household sample that adopted each simple practice. This data includes both simple and complex adopters as complex adopters could also adopt simple practices in addition to complex practices. Of the four-hundred households, 360 (90%) households stated they removed and destroyed infected leaves, shoots and fruits, 345 (86%) conducted regular field inspections to look for infestation of *Tuta absoluta*, 37 (9%) checked tomato seedlings for *Tuta absoluta* before transplantation, 94 (24%) did not grow other host crops and removed host weeds from their fields, and 288 (72%) destroyed previous host crop residue after the last harvest.

Figure 4.2: Adoption Rate of Individual Simple Practices

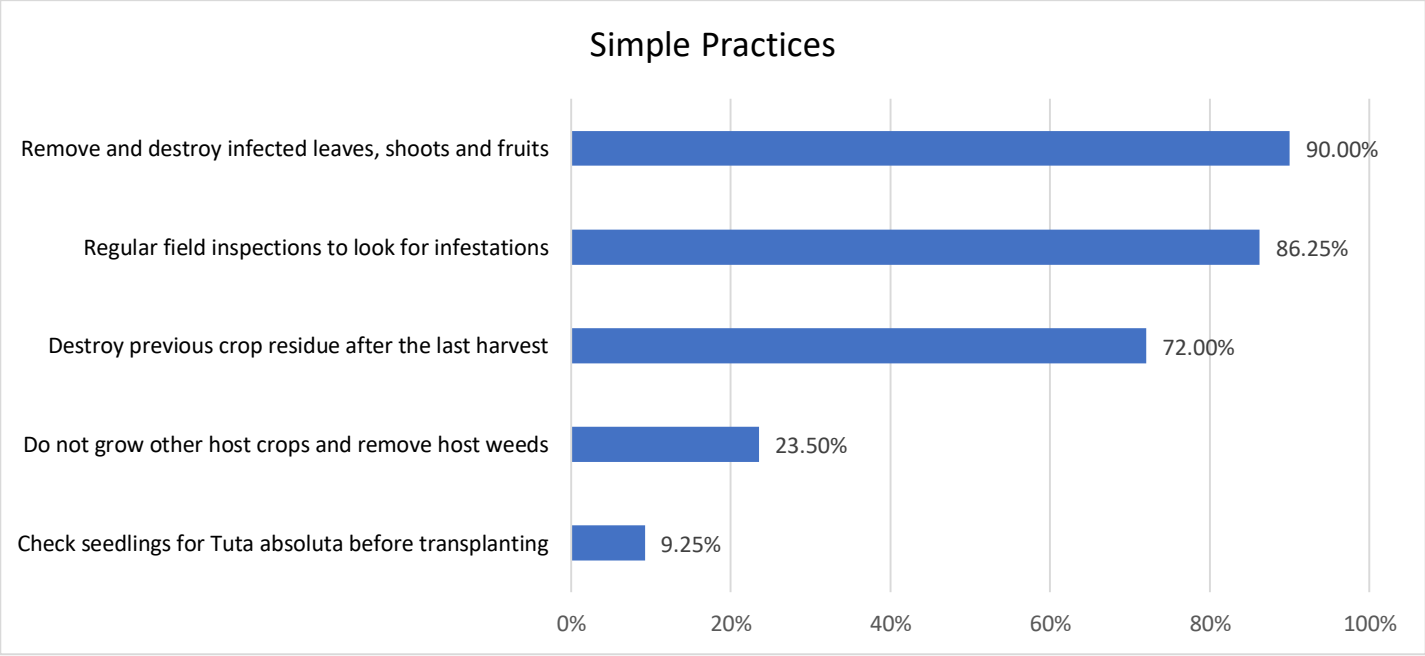
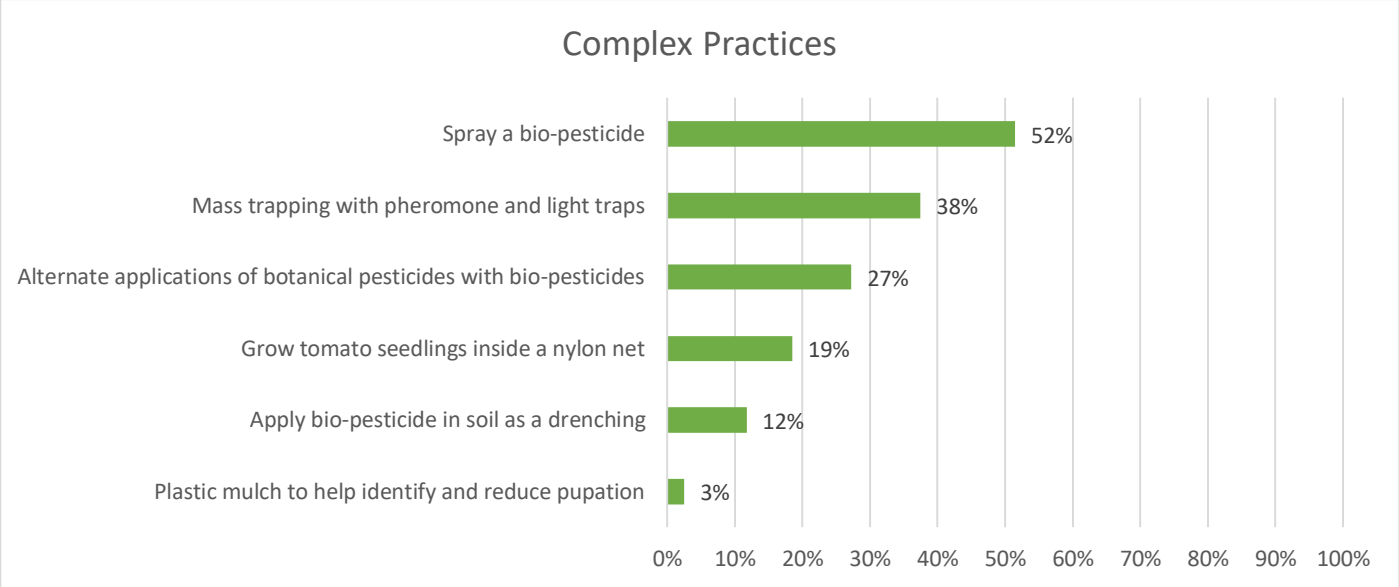


Figure 4.3 shows the portion of the household sample that adopted each complex practice. This data only includes complex adopters as simple adopters did not adopt any complex practices. Of the 314 households to adopt at least one complex practice, 109 (27%) use the method of alternating applications of botanical pesticides with bio-pesticides, 206 (52%) sprayed

a bio-pesticide on their tomato fields to control for *Tuta absoluta*, 150 (38%) mass trapped *Tuta absoluta* using either a pheromone or light trap, 10 (3%) used plastic mulch to help identify and reduce pupation of *Tuta absoluta*, 47 (12%) applied bio-pesticides in the soil as a drenching, and 74 (19%) grew tomato seedlings inside of a nylon net.

Figure 4.3: Adoption Rate of Individual Complex Practices



Summary statistics of the primary decision maker's/household's characteristics by adoption level were calculated in Table 4.1 below. In this table, non-adopters and simple adopters are grouped together as they are in the adoption variable. These statistics were generated by using the following commands in STATA: *tabulate variablename*; *tab variablename1 variablename2*, *row*; and *tab variablename1*, *summarize (variablename2)*

Table 4.1: Summary of the Primary Decision Maker's/Households Characteristics by Adoption Level

Variable	Description of Variables	Non-Adopter/Simple Adopter	Complex Adopters	All Households
district	Lalitpur Kaski Banke Surkhet	7 (8.14%) 14 (16.28%) 28 (32.56%) 37 (43.02%)	93 (29.62%) 86 (27.39%) 72 (22.93%) 63 (20.06%)	100 (25%) 100 (25%) 100 (25%) 100 (25%)
age	Mean	40.26 years	42.94 years	42.36 years
female	0=Male, 1=Female	25 (29.07%) 61 (70.93%)	92 (29.30%) 222 (70.70%)	117 (29.25%) 283 (70.75%)
educ	Mean	5.15 years	5.23 years	5.21 years
exper	Mean	6.33 years	6.49 years	6.46 years
migrant	0=No, 1=Yes	63 (73.26%) 23 (26.74%)	220 (70.75%) 117 (29.25%)	283 (70.75%) 117 (29.25%)
fmsz	Mean	7.68 ropani	8.47 ropani	8.30 ropani
houselab	Mean	3.84 laborers	4.18 laborers	4.11 laborers
landt	Mean	0.80 ropani	1.06 ropani	1.01 ropani
distag	Mean	10.83 kilometers	8.21 kilometers	8.78 kilometers
memb	0=No, 1=Yes	8 (9.30%) 78 (90.70%)	18 (5.73%) 296 (94.27%)	26 (6.50%) 374 (93.50%)
CBF	0=No, 1=Yes	49 (56.98%) 37 (43.02%)	152 (48.41%) 162 (51.59%)	201 (50.25%) 199 (49.75%)
media	0=No, 1=Yes	15 (17.44%) 71 (82.56%)	57 (18.15%) 257 (81.85%)	72 (18.00%) 328 (82.00%)
agcon	0=No, 1=Yes	14 (16.28%) 72 (83.72%)	36 (11.46%) 278 (88.54%)	50 (12.50%) 350 (87.50%)
personal	0=No, 1=Yes	2 (2.33%) 84 (97.67%)	21 (6.69%) 293 (93.31%)	23 (5.75%) 377 (94.25%)
train	0=No, 1=Yes	42 (48.84%) 44 (51.16%)	114 (36.31%) 200 (63.69%)	156 (39.00%) 244 (61.00%)
traintuta	0=No, 1=Yes	81 (94.19%) 5 (5.81%)	240 (76.43%) 74 (23.57%)	321 (80.25%) 79 (19.25%)
sev	0=No, 1=Yes	28 (32.56%) 58 (67.44%)	68 (21.66%) 246 (78.34%)	96 (24.00%) 304 (76.00%)

The 400 households were evenly distributed across the four districts: Lalitpur, Kaski, Banke, and Surkhet. The largest number of non-adopter/simple adopters reside in the Surkhet district (43.02%) while the smallest number reside in the Lalitpur district (8.14%). The opposite is true for the complex adopters. The largest number of complex adopters reside in the Lalitpur

district (29.62%) while the smallest number reside in the Surkhet district (20.06%). The average age of the 400 primary decision makers was 42.26 years. Of the non-adopters/simple adopters the average age was 40.26 years while of the complex adopters, the average age was 42.94 years. At all levels, the majority of primary decision makers were female: all households (70.75%), non/simple-adopters (70.93%), and complex adopters (70.70%). The table goes on to show the average education and experience at each level. The mean education level for all primary decision makers was 5.21 years. The mean for non/simple adopters (5.15 years) and complex adopters (5.23) did not deviate far from the overall mean. The average primary decision maker's level of tomato production experience had the same pattern as education in which non/simple adopters (6.33 years) and complex adopters (6.49 years) did not differ far from the household mean of 6.46 years. Migrant presence for all households (29.25%) was identical to the percentage of migrant households in the complex adopter's level. Non/simple adopters had a slightly lower percentage of migrant households (26.74%). Wealth was measured through a proxy variable of farm size. Number of laborers in the households follows a similar pattern to migrant statistics. Complex adopters (4.18 laborers) had a slightly larger number of household laborers than non/simple adopters (3.84 laborers). Average farm size in non/simple adopter's households was 7.68 ropani and complex adopter's households was slightly larger with 8.47 ropani. Of that land owned, we also measured land dedicated to tomato production. We saw minimal differences between non/simple households (0.80 ropani) and complex households (1.06 ropani). Household membership in organizations was slightly higher for complex adopters (94.27%) than for non/simple adopters (90.70%). Villages containing community business facilitators was fairly even for all households. Non/simple adopter's households had a higher percentage of non-CBF households (56.98%) while complex adopter's households were fairly

even between non-CBF (48.41%) and CBF households (51.59%). Advice from personal, media, and agricultural sources differed between levels. Media advice in non/simple adopters (82.56%) was slightly higher than for complex adopters (81.85%). Agricultural advice was slightly lower for non/simple adopters (83.72%) than for complex adopters (88.54%). Personal advice was also higher for non/simple adopters (97.67%) and complex adopters (93.31%). IPM training was more popular among the complex adopters (63.69%) than the non/simple adopters (51.16%). *Tuta absoluta* IPM training showed similar results but on a lower scale as only 23.57% of complex adopters attended *Tuta absoluta* IPM training(s) and only 5.81% of non/simple adopters attended.

4.1.2 Determinants of IPM Adoption

Four different regressions were run to analyze the determinants of *Tuta absoluta* IPM adoption in Nepalese tomato farmers. The differences were in the construction of the dependent variable (adoption); these differences were explained in section 3.3.1. The first regression was an instrumental variable probit model with a binary dependent variable. The second was an instrumental variable ordered probit model with a three level dependent variable. The third was a linear model with a continuous dependent variable of complex practices. The fourth was another linear model with a continuous dependent variable of all practices. It was decided that the probit model best served this project. This model allows us to examine the differences between the adoption of simple and complex practices. Also, compared to the instrumental variable ordered probit model, more is known and understood of the STATA commands for the probit model. Results for the other three model are shown in Appendix C.

The instrumental variable probit regression results are shown below in Table 4.2. Distance to agricultural extension office had a statistically significant and negative effect on

complex *Tuta absoluta* IPM adoption. Land dedicated to tomato production, membership status, *Tuta absoluta* IPM training, and severity of *Tuta absoluta* had a statistically significant and positive effect on complex *Tuta absoluta* IPM adoption. Age, gender, education level, experience level, household's migrant status, wealth, household labor, community business facilitator presence, advice from media source, advice from agricultural connections, advice from personal sources and IPM training did not show a statistically significant effect on complex *Tuta absoluta* IPM adoption.

Table 4.2: Adoption Model Regression Results and Average Marginal Effects

Variable	Coefficient	Standard Error	z	P>|z|	Average Marginal Effects	P>|z| of Marginal Effects
age	0.005	0.009	0.59	0.553	0.001	0.553
female	0.019	0.211	0.09	0.929	0.005	0.929
educ	0.010	0.021	0.47	0.637	0.003	0.637
exper	0.005	0.020	0.23	0.818	0.001	0.818
migrant	0.079	0.174	0.45	0.649	0.020	0.645
fmsz	0.168	0.234	0.72	0.474	0.043	0.474
houselab	0.035	0.042	0.84	0.400	0.009	0.399
landt	3.346	1.675	2.00	0.046**	0.859	0.042**
distag	-0.069	0.017	-4.03	0.000***	-0.018	0.000***
memb	0.480	0.291	1.65	0.099*	0.139	0.132
cbf	0.094	0.188	0.50	0.616	0.024	0.614
media	-0.183	0.205	-0.89	0.372	-0.045	0.350
agcon	-0.184	0.254	-0.72	0.469	-0.045	0.443
personal	-0.490	0.407	-1.20	0.229	-0.106	0.136
train	0.236	0.302	0.78	0.434	0.014	0.861
traintuta	0.931	0.439	2.12	0.034***	0.124	0.157
sev	0.425	0.174	2.45	0.014**	0.118	0.019**
constant	0.438	0.799	0.55	0.584		

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

Amount of land dedicated to tomatoes had a positive effect on adoption of complex practices and was statistically significant at the 5% level. The average marginal effect was also found to be positive and was also statistically significant at the 5% level. As the land dedicated to tomato production increased by one ropani, the probability of adoption of complex practices

increases 85.9 percent. The sign of this variable was consistent with our prediction. As more and more land is dedicated to tomato production, primary decision makers are more likely to care for the quality and quantity of their tomato production. Thus, they would be more likely to adopt complex IPM practices.

Household distance to the nearest agricultural extension office has a negative effect on IPM adoption and was statistically significant the 1% level. The marginal effect was also found to be negative and was also statistically significant at the 1% level. As household distance to the closest extension office increases by one kilometer, the probability of adoption of complex practices decreased 1.8 percent. The sign is consistent with our prediction thus confirming our expectation that the closer a household is to an agricultural extension office, the more likely they are to come in contact with an agricultural extension agent.

Primary decision maker's membership status has a positive effect on adoption and was statistically significant at the 10% level. However, the average partial effect is also positive but not statistically significant. This confirms our predictions of a positive relationship between membership and complex adoption. Information regarding IPM technology may be spread within these group thus causing an increase in adoption of complex IPM practices.

Tuta absoluta IPM training is shown to have a positive effect on adoption and was statistically significant at the 1% level. However, the average partial effect is also positive but not statistically significant. This matched our prediction that *Tuta absoluta* IPM training has a positive relationship with complex IPM adoption. Table 4.3 shows the source from which primary decision makers received IPM training relating to *Tuta absoluta*. Out of 400 households, 79 (19.25%) received *Tuta absoluta* IPM training. The most popular sources of training were

received from a CBF or NGO. It is important to note that primary decision makers may have indicated more than one source of training below.

Table 4.3: Source of *Tuta absoluta* IPM Training

	Agricultural Extension Office	Agro-vet	CBF	NGO	Farmer's Group	Total
Number of Households	9	6	53	52	1	79

Severity of *Tuta absoluta* on a household's tomato fields is shown to have a positive effect on adoption and was statistically significant at the 10% level. The average partial effect of severity was also seen to be statically significant at the 5% level. If a household reports *Tuta absoluta* having affected their tomato yields, the probability of adoption increases by 11.8 percent. Severity of damage could cause households to adopt more complex IPM practices. As more complex IPM practices are adopted, the damage caused by *Tuta absoluta* would decrease. Due to this specification error, severity could cause bias in the model. Additional discussion of the possible specification error occurs in section 5.2.

Age, gender, level of education, years of experience, presence of a migrant, wealth, household labor, and cbf presence's effect on adoption of complex practices was found to be positive but not statistically significant.

Advice received from media sources, agricultural sources, and personal sources all had a negative effect on adoption of complex practices but all were statistically insignificant. As advice received from media and personal sources could vary greatly based on the source of the advice, it was surprising to see agricultural sources have a negative effect on adoption of complex practices. Table 4.4 shows the descriptive statistics of advice received from agricultural

sources by adoption level. We see that non/simple adopters who did receive agricultural advice mostly received it from CBFs, NGOs, and Farmer's groups with a maximum percentage of 55.81% receiving advice from NGOs. The same is true for complex adopters with a maximum percentage of 59.55% receiving information from NGOs. Though we expect these sources to be promoting IPM practices, they may not be effectively doing so.

Table 4.4: Descriptive Statistics of Advice Received from Agricultural Sources by Adoption Level

Agricultural Source	Definition of Source	Non/Simple Adopters	Complex Adopters	All Adopters
Extension	0=No, 1=Yes	78 (90.70%) 8 (9.30%)	232 (73.89%) 82 (26.11%)	310 (77.50%) 90 (22.50%)
CBF	0=No, 1=Yes	48 (55.81%) 38 (44.19%)	152 (48.41%) 162 (51.59%)	200 (50.00%) 200 (50.00%)
NGO	0=No, 1=Yes	38 (44.19%) 48 (55.81%)	127 (40.45%) 187 (59.55%)	165 (41.25%) 235 (58.75%)
Field Day	0=No, 1=Yes	85 (98.84%) 1 (1.16%)	288 (91.72%) 26 (8.28%)	373 (93.25%) 27 (6.75%)
Farmer Field School	0=No, 1=Yes	85 (98.84%) 1 (1.16%)	275 (87.58%) 39 (12.42%)	360 (90.00%) 40 (10.00%)
Farmer's Group	0=No, 1=Yes	43 (50.00%) 43 (50.00%)	133 (42.36%) 181 (57.64%)	176 (44.00%) 224 (56.00%)

The effect of IPM training was positive but not statistically significant. The sign on this variable is consistent with our prediction. Table 4.5 below shows the descriptive statistics for IPM training based on adoption level. Primary decision makers are educated and given tools for IPM practices during IPM trainings, therefore it was expected that farmers who attend IPM trainings were to increase adoption of *Tuta absoluta* related complex IPM practices.

Table 4.5: Descriptive Statistics for IPM Training Based on Adoption Level

Variable	Definition of Source	Non/Simple Adopters	Complex Adopters	All Adopters
IPM training	0=Did not attend, 1=Did attend	42 (48.84%) 44 (51.16%)	114 (45.86%) 200 (63.69%)	156 (39.00%) 244 (61.00%)

4.2 Objective 2: Effects of Adoption on the Frequency of Pesticide Use

4.2.1 Frequency of Pesticide Use with Adopters and Non-Adopters

Of the 400 households, 190 (47.50%) households did not spend any expenditures on chemical pesticides to control for *Tuta absoluta* on their tomato fields. Of the 210 (52.50%) households who did spend expenditures applying chemical pesticides, the minimum expenditures spent on chemical pesticides was 150 rupees, the maximum was 20000 rupees, and the average of these 205 households was 2422 rupees. Of the 400 households, the average expenditures for chemical pesticides was 1272 rupees.

Table 4.6: Average Expenditures of Chemical Pesticides for Each Adoption Level

Variable	Description of Values	Average Expenditures Spent on Chemical Pesticides
adoption	0=Non/Simple adopters, 1=Complex adopters	1409 rupees 1234 rupees
adoption	0=Non-adopters 1=Simple adopters 2=Complex adopters	0 rupees 1864 rupees 1234 rupees

Table 4.6 above shows the average expenditures spent on chemical pesticide between non/simple adopters (1409 rupees) and complex adopters (1234 rupees) differed by 175 rupees with simple/non adopters spending more expenditures on chemical pesticides. This statistic was further broken down into three adoption categories: non-adopters, simple adopters, and complex adopters. In this study, non-adopters also claimed *Tuta absoluta* was not a present pest issue in their tomato production. Therefore, they did not spend any expenditures on chemical pesticides to control for *Tuta absoluta*. We examined the average expenditures spent on chemical pesticide between the three new levels of adoption. Since the only change was with the non/simple adopters level, complex adopter's amount of expenditures on chemical pesticide did not change.

The second adoption variable in Table 4.6 shows an increase in simple-adopters (1864 rupees) compared to the simple/non-adopters (1409 rupees) in the two-level adoption variable.

Table 4.7: Descriptive Statistics of Average Expenditures Spent on Chemical Pesticides

Variable	**Description of Values**	**Mean Amount of Expenditures Spent on Chemical Pesticides**
district	Lalitpur Kaski Banke Surkhet	1837 rupees 201 rupees 1143 rupees 1906 rupees
hiredlabor	0=No, 1=Yes	1215 rupees 6925 rupees
sev	0=Yield not affected, 1=Yield affected	513 rupees 1511 rupees

Table 4.7 above shows the average amount of expenditures spent on chemical pesticides to control for *Tuta absoluta* between districts. The highest average expenditures were in the Surkhet district (1906 rupees) and the lowest average in the Kaski district (201 rupees). Of the 400 households, households who hired labor to apply chemical pesticides (6925 rupees) had a large increase in the amount of expenditures sent on chemical pesticides versus households who did not hired additional labor (1215 rupees). The average amount of expenditures spent on chemical pesticides also varied between households who stated *Tuta absoluta* affected their tomato yield (1511 rupees) and households who stated their tomato yield was not affected (513 rupees).

4.2.2 Pesticide Model Results

Results from the pesticide model used to determine the factors that influence expenditures spent chemical pesticide are shown below in Table 4.8. Age, gender, and education level had a statistically significant and negative effect on the amount of expenditures spent on chemical pesticides. IPM adoption, land dedicated to tomato production and severity of *Tuta absoluta* had a statistically significant and positive effect on the amount of expenditures spent on chemical pesticides. Experience level, wealth, household labor, community business facilitator presence, advice received from media sources, advice received from agricultural sources, advice received from personal sources and hired labor did not have a statistical significant effect on the amount of expenditures spent on chemical pesticides.

Table 4.8: Pesticide Use Model Regression Results

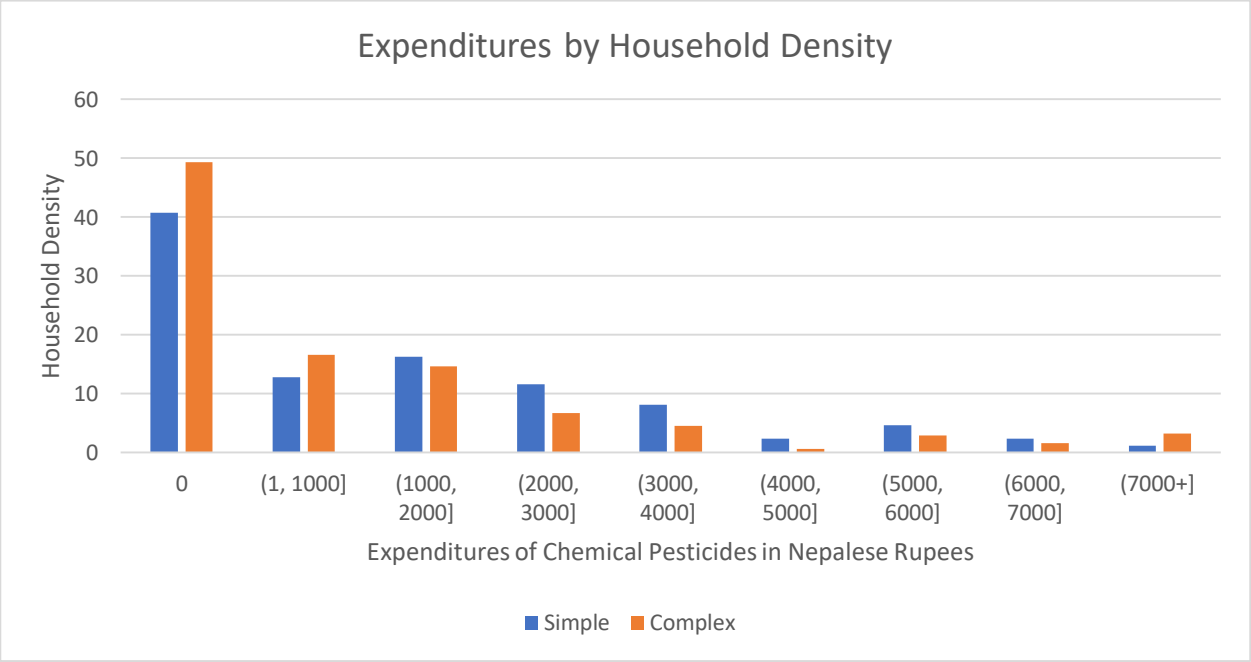
Variable	Coefficient	Standard Error	z	P>|z|
adopt	1840.43	1015.147	1.81	0.070*
age	-46.80	12.325	-3.80	0.000***
female	-707.96	289.569	-2.44	0.014**
educ	-95.929	30.867	-3.11	0.002***
exper	3.449	25.622	0.13	0.893
fmsz	3.812	16.663	0.23	0.819
houselab	9.994	58.183	0.17	0.864
landt	573.133	65.678	8.73	0.000***
cbf	-252.505	235.706	-1.07	0.284
media	-378.470	287.185	-1.32	0.188
agcon	220.044	349.783	0.63	0.529
personal	-426.447	474.467	-0.90	0.369
hiredlabor	1232.19	1168.072	1.05	0.291
sev	569.486	24.092	2.08	0.038**
Constant	3046.746	1166.709	2.61	0.009

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

Complex IPM adoption had a positive effect on the amount of expenditures spent on chemical pesticides and was statistically significant at the 10% level. If the household adopted at least one complex IPM practices, the household was likely to spend an additional 1840 rupees on

chemical pesticides to control for *Tuta absoluta*. Contrary to our prediction, adopting complex IPM practices may cause household to spend more on chemical pesticides. As previously stated, one goal of implementing IPM practices was to decrease the need for chemical pesticides. Results from this analysis shows a lack of understanding of proper IPM technologies and a need for further education of chemical pesticide use in tandem with IPM practices. Figure 4.5 shows the difference of expenditures by household density of each adoption level. We see higher household densities of complex-adopters in lower levels of expenditures. As the graph progresses, household densities of simple/non-adopters become larger than complex-adopters.

Figure 4.4 Expenditures by Adoption Level Household Density



Age had a negative effect on the amount of expenditures spent on chemical pesticides and was statistically significant at a 1% level. As the age of the primary decision maker increased by 1 year, the average amount of expenditures spent on chemical pesticides decreased by 46 rupees. Contrary to our prediction, the older a primary decision maker is, the less expenditures they are

likely to spend on chemical pesticides. This may be due to older farmers applying a smaller amount of chemical pesticides to reduce the labor required for tomato production.

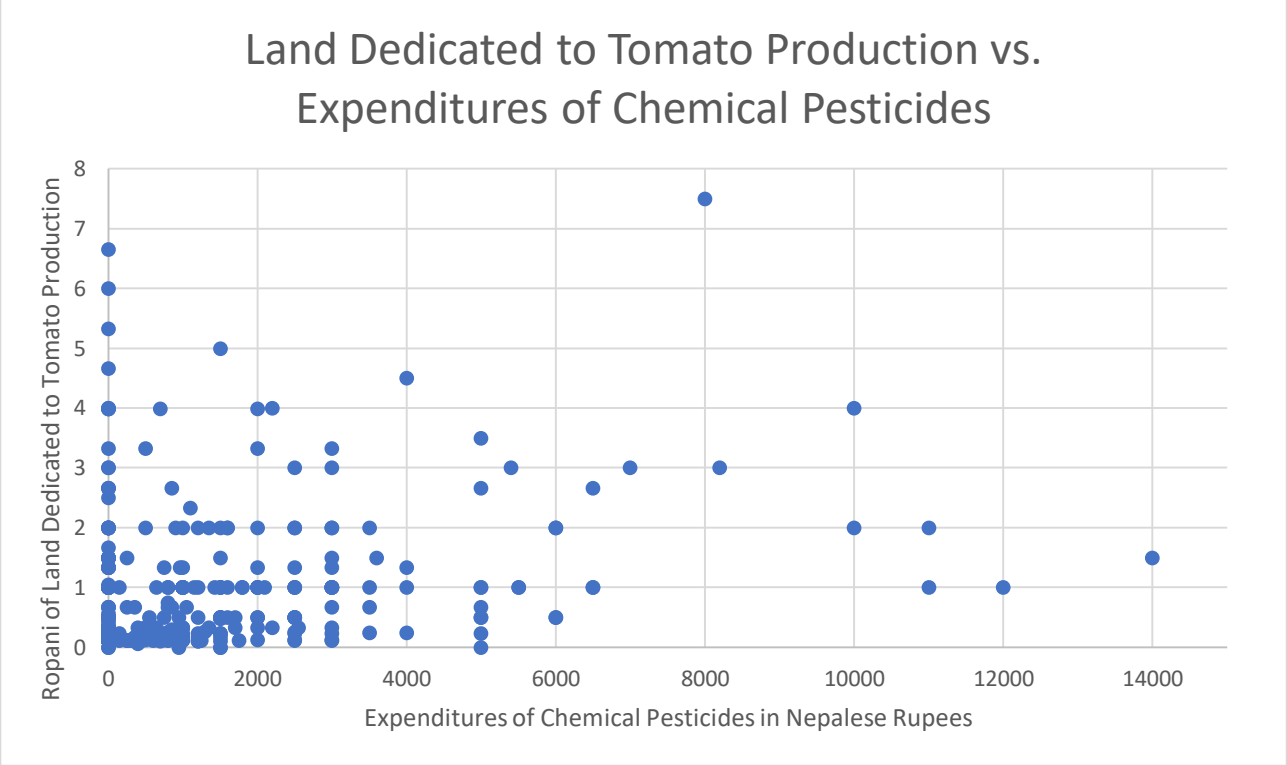
Gender had a negative effect on the amount of expenditures spent on chemical pesticides and was statistically significant at the 1% level. If the primary decision maker was female, the average amount of expenditures spent of chemical pesticides decreased by 708 rupees. This may be explained by female primary decision makers weighing the health risks of chemical pesticides greater than men primary decision makers do.

Education had a negative effect on the amount of expenditures spent on chemical pesticides and was statistically significant at the 1% level. If the primary decision maker's level of education increased by 1 year, the average amount of expenditures spent on chemical pesticides decreased by 96 rupees. As education level increases, the average amount of expenditures spent on chemical pesticides may decrease due to the primary decision maker investing more time and energy in learning about chemical pesticides and other pest control alternatives. Higher educated primary decision makers may also understand proper chemical pesticide application procedures; therefore, avoid over applications and spend less expenditures on chemical pesticides.

The number of ropani dedicated to tomato production had a positive effect on the amount of expenditures spent on chemical pesticides and was significant at the 1% level. If the number of ropani dedicated to tomatoes increased by 1 ropani, the average amount of expenditures spent on chemical pesticides increased by 573 rupees. This result was inconsistent with our prediction. This may be explained by risk. We expected households with a larger amount of land dedicated to tomato production to care more about the quality and quantity of their production. If primary decision makers were familiar with chemical pesticides and they were risk adverse, they may be

more likely to keep using their known pest control methods to avoid any risk of yield loss. Figure 4.4 shows the density of household land dedicated to tomato production verses the amount of expenditures spent on chemical pesticides to control for *Tuta absoluta*. In general, we saw a greater variation in the expenditures of chemical pesticides in households with a smaller portion of land dedicated to tomatoes. A greater range was seen in households with a larger portion of land dedicated to tomatoes.

Figure 4.5: Land Dedicated to Tomato Production vs. Expenditures of Chemical Pesticides



Severity of *Tuta absoluta* was significant at the 1% level and had a positive effect on the amount of expenditures spent on chemical pesticides. If primary decision makers indicated their yield was affected by *Tuta absoluta*, the average amount of expenditures spent on chemical pesticides increased by 569 rupees. As in the adoption model, severity may present positive due to a specification error. Severity of damage could cause households to spend more expenditures

on chemical pesticides. More expenditures spent of chemical pesticides would lead to more chemical pesticide applications; Thus decreasing *Tuta absoluta* damage.

Advice received from agricultural sources had a positive relationship with the amount of expenditures spent on chemical pesticides but was not statistically significant. Table 4.10 shows the summary statistics of expenditures spent on chemical pesticides by agricultural advice sources. Advice received from agricultural extension, field days, and farmer field schools all show a greater average number of expenditures when no advice is given. However, advice received from non-governmental agencies (NGOs) and farmer's groups shows a higher average expenditures spent on chemical pesticides when farmers receive advice from those sources. Households who receive advice from a CBF show a similar amount of expenditures spent as those households who did not receive advice from CBFs.

Table 4.9: Average Expenditures Spent on Chemical Pesticides by Advice Received from Individual Agricultural Sources

Agricultural Source	Average Expenditures Spent on Chemical Pesticides with No Advice from Source	Average Expenditures Spent on Chemical Pesticides with Advice from Source
Extension	1335 rupees	1053 rupees
CBF	1306 rupees	1237 rupees
NGO	1146 rupees	1360 rupees
Field Day	1341 rupees	309 rupees
Farmer Field School	1367 rupees	410 rupees
Farmer's Group	1107 rupees	1401 rupees

CBF presence, wealth advice received from media sources and advice received from personal sources had a negative effect on the amount of expenditures spent on chemical pesticides to control for *Tuta absoluta* and was not found statistically significant. Level of

experience, wealth, household labor, and hired labor had a positive but insignificant impact on the amount of expenditures spent on chemical pesticides to control for *Tuta absoluta.*

Chapter 5: Conclusion

5.1 Summary and Policy Recommendations

The two main objectives of this study were: to determine the extent of adoption of IPM practices applied to manage *Tuta absoluta* in major tomato growing districts of Nepal and factors that influence adoption of those practices and to compare the frequency of pesticide use for *Tuta absoluta* by tomato farmers who adopt *Tuta absoluta* IPM practices with the frequencies by farmers who do not adopt the practices. 401 households were randomly selected and surveyed using the questionnaire in Appendix B. One household was dropped. For the remaining households, analyses were conducted for each objective listed above.

In section 4.1.1, we examined the extent of adoption of IPM practices applied to manage *Tuta absoluta*. Of the 400 households, 379 households adopted at least one IPM practice. The 21 households who did not adopt any IPM practices did not encounter *Tuta absoluta* in their tomato fields. Therefore, if a household encountered *Tuta absoluta* in their tomato field, they adopted at least one IPM practice. On the surface, IPM adoption seems to have a high success rate. After looking further into each IPM practice, we see that IPM practices can be divided into two groups: simple and complex. Complex practices require additional knowledge and inputs compared to simple practices. Of the 379 households with *Tuta*, 65 adopted at least one simple practices and no complex practices while the remaining 314 households adopted at least one complex practice. For the 314 complex-practice adopters, the most popular complex practice was the use of bio-pesticides (52%). The most utilized simple practice was the removal of infected leaves, shoots, and fruits (90% of adopters).

For the second part of the first objective we wanted to determine the factors that influence adoption of complex IPM practices. An instrumental variable probit model was utilized

for this analysis. Two variables, $train\ and\ traintuta$, were determined to cause an endogeneity issue and thus instrumental variables were constructed and implemented. The binary adoption variable was defined as zero for non/simple adopters and one for complex adopters. Results of this analysis found five statistically significant variables with effects on the adoption of complex practices: ropani dedicated to tomato production, household distance to nearest agricultural extension office, membership status of primary decision maker, IPM training relating specifically to *Tuta absoluta*, and severity of *Tuta absoluta* in household tomato fields.

Results of this analysis showed household distance to nearest agricultural extension office was a significant determinant to decrease the likelihood of the adoption of complex practices when all other determinants were held constant. Ropani dedicated to tomato production, membership status of primary decision makers, IPM training regarding *Tuta absoluta* practices and severity of *Tuta absoluta* were significant determinates to increase the likelihood of the adoption of complex practices when all other determinates were held constant. If Nepal wanted to increase adoption of complex IPM practices targeted towards *Tuta absoluta*, we recommend targeting households who dedicated more land to tomato production, are located nearest an agricultural extension office, who attend at least one *Tuta absoluta* targeted IPM training, are part of a part of a farm or community organization and express *Tuta absoluta* damage in their tomato fields.

IPM training relating to *Tuta absoluta* increases the likelihood of adoption of complex practices. Of the 400 primary decision makers surveyed, only 79 (19.25%) attended a IPM training related to *Tuta absoluta*. The two top sources of training were CBFs and NGOs. We suggest Nepal focus on furthering *Tuta absoluta* IPM trainings through these sources to further promote adoption of complex IPM practices relating to *Tuta absoluta*.

For the second objective, we compare the frequency of pesticide use for *Tuta absoluta* by tomato farmers who adopt *Tuta absoluta* IPM practices with frequencies by farmers who do not adopt the practices. We found the average number of worker days per ropani spent applying chemical pesticides to be 5.10 days for non/simple adopters and 4.08 days for complex adopters. All non-adopters did not report spotting *Tuta absoluta* in their tomato fields. Therefore, they did not spend any worker days applying chemical pesticides to their tomato fields to control for *Tuta absoluta*.

A linear regression was utilized to examine the determinants of the amount of expenditures spent on chemical pesticides to control for *Tuta absoluta* in tomato fields. Regression results found six statistically significant variables that affect the amount of expenditures spent on chemical pesticides: IPM adoption, age, gender, education, land dedicated to tomato production, and severity of *Tuta absoluta*. For this study we were particularly interested in the effect of adoption of IPM practices on the frequency of pesticide use. Regression results show adoption had a positive and significant effect on IPM adoption. This result was contrary to our predication but gives insight on farmer understanding on the relationship between IPM practices and chemical pesticides. This result shows a need for further education of the goals and purposes of IPM practices. We saw agricultural advice received from agricultural extension agents, CBFs, NGOs, and farmer groups did not show large differences between the average expenditures spent on chemical pesticides of farmers who did receive advice and those who did not. We recommend training/education to these advice sources so that farmers who receive advice from these sources can fully understand the benefits of IPM practices and the decreased need for chemical pesticides when they are adopted.

5.2 Limitations & Extensions

The variable cbf may have caused an endogeneity issue within the adoption and pesticide model. Half (20) of the sampled villages contained a community business facilitator. Sources from iDE Nepal stated CBFs were placed in villages based on the village need for agricultural inputs. Due to the non-randomized nature of the CBF placement, an endogeneity issue could have been possible since other factors may have influenced CBF village selection. Unlike the other endogenous variables in the adoption model, the CBF status of a village was determined at a village level rather than a household level. Constructing an instrumental variable model for the CBF variable would pose challenges as the model may have been mis-specified due to missing variables. Also, the sample size constricts to 40 villages since CBF selection is a village level variable.

Another variable that may have caused potential issues within the adoption and pesticide model was severity of *Tuta absoluta*. Severity acts as a pest indicator variable. The presence of *Tuta absoluta* damage to tomato yields was constructed as a binary variable based on the affect to tomato yields. Though correlation of severity to adopt or worker days (seen in Appendix C9 & C11) was not present, the structure of the variable may have caused an issue. As the incident of damage from *Tuta absoluta* increased, farmers needed to apply some method of pest control to their tomato fields. But, if farmers were to apply a pest control method, then the damage from *Tuta absoluta* was likely to decrease, thus decreasing the need to use any pest control method.

This baseline survey created a cross-sectional data set. Cross-sectional data sets are useful in the evaluation of determinants of adoption if and when adoption is at higher rates. Fortunately, in this case, adoption of IPM practices relating to *Tuta absoluta* control was found to be at a high rate. Extensions to this project could be made to further examine the retention of

adoption of those IPM practices and the resiliency of farmers to *Tuta absoluta* by furthering data collection in subsequent years to create a panel data set.

If this extension were to be done, survey modifications may enhance data collection. Many questions could use more specification as to time frames and locations. For example, questions regarding IPM training asked if the primary decision maker had ever attended an IPM training. An addition of a time-frame, such as asking if primary decision makers attended IPM trainings within in the past three years, could result in a more precise and relevant data point.

5.3 Conclusion

This study provided information regarding the extent and determinates of adoption for *Tuta absoluta* specific IPM practices and their effects on chemical pesticide usage in the Lalitpur, Kaski, Banke and Surkhet districts of Nepal. At a surface level, *Tuta absoluta* IPM adoption seems to have a high adoption rate for farmers who identified *Tuta absoluta* on their farm. Looking more deeply into the data, we discovered 314 (79%) of the households adopted at least one IPM practices that required additional knowledge and/or agricultural inputs.

To further increase the probability of adoption of complex IPM practices related to *Tuta absoluta*, Nepal should focus on increasing *Tuta absoluta* focused IPM training throughout the districts of Nepal that have detected and identified *Tuta absoluta*. Increased participation in these trainings could increase the likelihood of adoption of complex practices. Nepal should also target farm-households who dedicate larger plots of land to tomato production and who are located nearest extension offices in order to increase the likelihood of complex IPM practices. Community or farm organizations should also be a key point of communication for iDE Nepal to promote *Tuta absoluta* focused IPM practices.

Adoption of complex IPM practices did positively influence the amount of expenditures spent on chemical pesticides to control for *Tuta absoluta*. This was a surprising discovery given one goal of the *Tuta absoluta* IPM project was to decrease the need for chemical pesticide use with increase adoption rates. Education of *Tuta absoluta* IPM practices needs to be examined if Nepal's goal for IPM adoption is to reduce the number of calendar applications of chemical pesticides throughout tomato fields of Nepal. More emphasis needs to be placed on the benefits of IPM practices and the effects of chemical pesticide usage. Nepal has a great potential to increase the adoption of complex IPM practices regarding *Tuta absoluta* and decrease the number of calendar based chemical pesticide applications if proper education is administered.

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Appendix A: List of Abbreviations

IPM IL	Integrated Pest Management Innovation Lab
CBF	Community Business Facilitator
GDP	Gross Domestic Product
Tuta	*Tuta absoluta*
IPM	Integrated Pest Management
OLS	Ordinary Least Squares
MLE	Maximum Likelihood Estimation
IV	Instrumental Variable
2SLS	Two-Stage Least Squares
NGO	Non-governmental agency

Appendix B: Questionnaire

IPM Innovation Lab Nepal

Interview Questionnaire

2018

ALL INFORMATION CONTAINED IN THIS QUESTIONNAIRE IS STRICTLY

CONFIDENTIAL

SECTION 1: METADATA

	NAME	CODE
INTID: ENUMERATOR ID		[__|__|__]
DISTRICT: NAME AND CODE OF DISTRICT		[__|__|__]
VILLAGE: NAME AND CODE OF VILLAGE		[__|__|__]
HHID: NAME AND CODE OF HOUSEHOLD		[__|__|__]

1. INTERVIEW DATE AND TIME	[__|__][__|__] 2018 **DAY/MONTH/YEAR**
2. TIME INTERVIEW STARTED	[__|__][__|__] **HH MM**
3. TIME INTERVIEW FINISHED	**[__|__][__|__]**
	HH MM
4. RESULT (SEE LIST BELOW)	**[__]**
RESULT 1 = COMPLETE 2 = NOT COMPLETE (RETURN TO HOUSEHOLD) 3 = NOT AVAILABLE 4 = REJECTION 5 = COULD NOT LOCATE HOUSEHOLD 6 = DID NOT GROW TOMATOES 99 = OTHER (SPECIFY)_____	
QUALITY CONTROL	
5. DATE, INTERVIEW SUPERVISOR	[__|__][__|__] 2018
	DAY MONTH YEAR
6. **RESULT, SUPERVISOR (CIRCLE ANSWER)**	1 = COMPLETE (SEND TO VA TECH) 2 = NOT COMPLETE (RETURN TO HOUSEHOLD) 3 = NOT AVAILABLE 4 = REJECTION 5= COULD NOT LOCATE HOUSEHOLD 6 = DID NOT GROW TOMATOES 99 = OTHER (SPECIFY)

SECTION 2: LOCATING HOUSEHOLD AND OBTAINING CONSENT

No	QUESTIONS	CODES/RESPONSES	GO TO
INTERVIEWER: YOUR <u>FIRST</u> JOB IS TO <u>LOCATE</u> THE HOUSEHOLD AND FARMER THAT WAS IDENTIFIED IN THE LIST TO BE INTERVIEWED. YOUR <u>SECOND</u> JOB IS TO ASCERTAIN WHO THE PRIMARY PERSON IS IN THE HOUSEHOLD WHO MAKES DECISIONS WITH RESPECT TO TOMATO PRODUCTION. THAT IS THE PERSON WHO SHOULD BE INTERVIEWED. YOUR <u>THIRD</u> TASK IS TO <u>OBTAIN CONSENT</u> FOR THE INTERVIEW. IF YOU CANNOT FIND THE HOUSEHOLD OR THE FARMER IS NO LONGER IN THE VILLAGE, NOTE THE REASON WHY. THESE QUESTIONS WILL HELP TO DETERMINE WITH WHOM (OR IF) THE INTERVIEW WILL BE CONDUCTED.			
1	**WERE YOU ABLE TO LOCATE THE HOUSE?**	No……..……0 Yes……..……..1	**>Q4** **>Q2**
2	Please write down the correct **latitude of the housed.**	**[USE GPS DEVICE]: _____**	
3	Please write down the correct **longitude of the house.**	**[USE GPS DEVICE]: _____**	
INTERVIEWER: READ THE FOLLOWING STATEMENT TO THE FARMER: "WE ARE CONDUCTING A SURVEY OF PEST PROBLEMS AND PEST MANAGEMENT PRACTICES IN TOMATO PRODUCTION IN YOUR VILLAGE AS PART OF A PROJECT AIMED AT REDUCING PEST PROBLEMS. RESPONDING TO QUESTIONS ON THIS SURVEY IS VOLUNTARY. IF YOU AGREE TO RESPOND, YOUR ANSWERS WILL REMAIN ANONYMOUS. DO YOU CONSENT TO RESPOND?"			
4	Did your farm grow tomatoes in the past 12 months?	No…….1 Yes……2	**>STOP** **>Q5**
5	Who makes the primary decisions with respect to tomato production on your farm? (**Ask to interview the primary decision maker(s)**)	Mostly Myself ……..……..……..……..1 Mostly My Spouse…….2 Myself and My Spouse Equally…..……..……...3 Father-in-law or Mother-in-law…….4 Father or Mother……5 Other (Specify)_____.....99	
6	**DOES THE FARMER (HE/SHE/THEY) CONSENT TO BEING INTERVIEWED?**	No, rejects interview……..……0 Yes, accepts interview……..…….1 **(THANK THE FARMER FOR AGREEING TO PARTICIPATE)**	**>STOP** **>Q7**
7	**INDICATE IF TWO PEOPLE ARE INTERVIEWED TOGETHER**	Man interviewed……..1 Woman interviewed……2 Two people interviewed…….....3	
8	**NAME OF THE FARMER BEING INTERVIEWED**	**(WRITE DOWN NAME):_____**	**>SEC3**

SECTION 3: DEMOGRAPHIC INFORMATION

No	QUESTIONS	CODES/RESPONSES	GO TO
INTERVIEWER: SAY TO THE FARMER: I WOULD FIRST LIKE TO ASK YOU QUESTIONS ABOUT YOURSELF AND YOUR FAMILY.			
1	Do you have a phone?	No……..……..……0 Yes…….....……..1	**>Q3** **>Q2**
2	What is your phone number?	Phone number:_____	
3	What is your age?	[___|___] Years	
4	Male or female? **[MAY NOT NEED TO ASK]**	Male……..……1 Female……..……2	
5	What is your marital status?	Married …….....…….1 Single or never married……..…2 Widow/widower……..……3 Separated/Divorced……..……..4 Other……..99	**>Q6** **>Q7** **>Q7** **>Q7** **>Q7**
6	What is your spouse's age?	[___|___] Years	
7	What is your primary occupation?	Farming (any type)……..…1 Business……..……....2 Salary/Wage Job…….……....3 Other (specify)._____.....99	
8	What is your secondary occupation? **[NOTE SECONDARY OCCUPATION CANNOT BE SAME AS PRIMARY]**	Farming (any type)……...…1 Business……..……..……....2 Salary/Wage Job…….……....3 Other (specify)._____.....99 No secondary occupation…..……..……4	
9	Has the farmer ever attended school?	No……..……0 Yes……..……..1	**>Q11** **>Q10**
10	How many total years of schooling have you completed (number of years)?	[___|___] Years	
11	Can you read?	No……..……0 Yes……..……..1	
12	Can you write?	No……..……0 Yes……..……..1	
13	How many years of experience do you have with tomato cultivation?	[___|___] Years	
	How many family members live in your house (live under same roof)?		

14	….Number of male members?	[___|___]	
15	…Number of female members?	[___|___]	
16	How many of these family members work or are able to work? **(Q16 CANNOT BE GREATER THAN Q14 AND Q15)**	[___|___]	
17	Does any member of the household migrate to another country for work?	No…….0 Yes……1	**>Q19** **>Q18**
18	How long does any member migrate for work?	Seasonal (Six months or less)……...….1 Long-term (More than six months)……2	
19	Has the farmer's spouse ever attended school? (**IF MARRIED**)	No……..……0 Yes……..……..1	**>Q21** **>Q20**
20	How many years of schooling has the farmer's spouse completed? (**IF MARRIED**)	[___|___] Years	
21	Can the farmer's spouse read? **(IF MARRIED)**	No……..……0 Yes……..……...1 Does not know...…….……88	
22	Can the farmer's spouse write? **(IF MARRIED)**	No……..……0 Yes……..……..…..1 Does not know...…….……88	
23	How far is your major tomato field from the nearest location where you sell tomatoes? (**If they sell in the field, put zero)**	[___|___].[___|___] Kilometers	
24	How far is your house from the nearest agricultural extension office?	[___|___].[___|___] Kilometers	
25	How far is your house from the nearest agro-vet store?	[___|___].[___|___] Kilometers	
26	How far is your village from the closest market?	[___|___].[___|___] Kilometers	
27	Did you need to borrow a loan for your tomato production last year?	No……..……0 Yes……..……..1	**>SEC4** **>Q28**
28	Was your household able to borrow the amount it needed?	No……..……0 Yes……..……..1	

SECTION 4: LAND ASSETS AND USAGE

No	QUESTIONS	CODES/RESPONSES	GO TO
INTERVIEWER: SAY TO THE FARMER: NOW I WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT YOUR LAND AND THE LAND YOU ARE FARMING.			

1	How much land (in Ropani/Katha) you own? (**Indicate Units Below**)	[___|___].[___|___] **IF NONE WRITE 0**	
a	Indicate Units	Ropani……1 Katha……..2	
2	How much land (in Ropani/Katha) do you devote to tomatoes in the monsoon season?	[___|___].[___|___] **IF NONE WRITE 0**	
3	How much land (in Ropani/Katha) do you devote to tomatoes in the Winter season (November-March)?	[___|___].[___|___] **IF NONE WRITE 0**	
How much of the land (in Ropani/Katha) on which you and your household members currently plant tomatoes...			
4	…..is owned by the household?	[___|___].[___|___] **IF NONE WRITE 0**	
5	…. is rented in?	[___|___].[___|___] **IF NONE WRITE 0**	
6	.... mohiyani?	[___|___].[___|___] **IF NONE WRITE 0**	
7	….is farmed by other means?	[___|___].[___|___] **IF NONE WRITE 0**	
8	Specify the type of other means	Specify:_____.....99	

SECTION 5: ORGANIZATION OR GROUP MEMBERSHIP

No	QUESTIONS	CODES/RESPONSES	GO TO
INTERVIEWER: SAY TO THE FARMER: NOW I WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT THE ORGANIZATIONS AND GROUPS YOU BELONG TO.			
1	Are you or another family decision maker a member of any farm organization or community organization?	Self a member……..……..……1 Spouse a member……..……..…...2 Other family decision maker a member.....3 Neither a member…….....…..4	**>SEC6**
2	Are you or another family decision maker a member of savings group?	Self a member……..…..……1 Spouse a member……..……..…...2 Other family decision maker a member.....3 Neither a member……..…..4	
3	Are you or another family decision maker a member of a marketing cooperative or	Self a member……..……1 Spouse a member……..……..……..…...2 Other family decision maker a member.....3	

	marketing group/collection center?	Neither a member……..…..4	
4	Other group? (specify)	Specify the type of other:_____.....99	

SECTION 6: AGRICULTURAL KNOWLEDGE SOURCES

No	QUESTIONS	CODES/RESPONSES	GO TO
INTERVIEWER: SAY TO THE FARMER: NOW I WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT THE HOW YOU RECEIVE ADVICE AND OR LEARN ABOUT AGRICULTURE			
	In the past 2 years, have you received advice and/or learned about agriculture from……[**READ LIST]**		
1	…….a government agricultural extension worker or center?	No……..……0 Yes……..……..1	
2	……Community business facilitator (CBF)?	No……..……0 Yes……..……..1	
3	…….an NGO agricultural extension worker?	No……..……0 Yes……..……..1	
4	…….Relatives?	No……..……0 Yes……..……..1	
5	…….Neighbor, friend, or lead farmer?	No……..……0 Yes……..……..1	
6	…….Field day?	No……..……0 Yes……..……..1	
7	…….Farmer field school?	No……..……0 Yes……..……..1	
8	…….Seed/pesticide/ fertilizer salesperson?	No……..……0 Yes……..……..1	
9	…….Radio?	No……..……0 Yes……..……..1	
10	…….Television or video?	No……..……0 Yes……..……..1	
11	…..Newspaper/Leaflet?	No……..……0 Yes……..……..1	
12	…….Mobile phone message?	No……..……0 Yes……..……..1	
13	…….Farmers' group?	No……..……0 Yes……..……..1	
14	……..Social media such as Facebook?	No……..……0 Yes……..……..1	

15	.....Agricultural mobile apps	No……..……0 Yes……..……..1	
16	…….Other means not previously mentioned?	No……..……0 Yes……..……..1	
17	Specify the other means	_____...99	
18	What are your two most important sources of agricultural information or advice?	Specify: 1._____...99 2._____...99	

SECTION 7: PRODUCTION, PESTS, PEST MANAGEMENT, AND CHEMCIAL PESTICIDE USE OF TOMATO CROP IN WINTER SEASON (NOVEMBER – MARCH).

No	QUESTIONS	CODES/RESPONSES	GO TO
INTERVIEWER: SAY TO THE FARMER: NOW I WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT PESTS, PEST MANAGEMENT, AND CHEMCIAL PESTICIDE USE IN YOUR TOMATO PRODUCTION DURING THE PREVIOUS WINTER SEASON (NOVEMBER – MARCH).			
In the previous winter season (November – March)...			
1	How many **Ropani/Katha** did you plant of tomatoes? [**IF DID NOT GROW, WRITE 0]**	[___|___].[___|___]	**>IF 0, GO TO SEC 8**
2	What was your total **production** of tomatoes produced (in kilos)?	[___|___|___|___].[___|___]	
3	What was the total **value** of the tomatoes sold (in Nepalese rupees)?	[___|___|___|___|___|___] Nepalese rupee	
4	Did you produce tomatoes in a net house?	No…….0 Yes……1	**>Q8**
5	How many **Ropani/Katha** did you plant of tomatoes in net house?	[___|___].[___|___]	
6	What was your total **production** of tomatoes produced in your net house (in kilos)?	[___|___|___|___].[___|___]	
7	What was the total **value** of the tomatoes sold from those produced in a net house (in Nepalese rupees)?	[___|___|___|___|___|___] Nepalese rupee	
8	What proportion of your tomato yield did you lose due to insect and worm pests?	None……..…..…….0 Some, but one fourth or less……..……..…….1 More than one fourth but less than half..…….…..2 More than one half but less than three fourths…...…3	

		More than three fourths……...4	
9	What proportion of your tomato yield did you lose due to disease/viruses?	None……..…..…….0 Some, but one fourth or less……..…….....…….1 More than one fourth but less than half...…….…..2 More than one half but less than three fourths…...…3 More than three fourths……...4	
10	Did you encounter the tomato pest *Tuta absoluta*? (**SHOW PICTURES**)	No……..……..……..0 Yes…….....…….……1	**>Q18**
11	How severe was *Tuta absoluta*?	None ……..……0 Low (some damage, yield not affected)….……...1 Medium (some damage, yield affected)….……...…2 High (major damage and effect on yield)…….....3	**>Q13** **>Q13** **>Q12** **>Q12**
12	What proportion of your tomato yield did you lose due to *Tuta absoluta*?	None……..…..…….0 Some, but one fourth or less……..…….....…….1 More than one fourth but less than half...…….…..2 More than one half but less than three fourths…...…3 More than three fourths……...4	
13	Which of the following practices, if any, did you use to control *Tuta absoluta* in a net house setting? **(CIRCLE ALL THAT APPLY)**	None……1 Grow seedlings inside a netted nursery……...……2 Destroy previous crop residue after last harvest…….....3 Do not grow other host crops and remove host weeds….4 Apply bio-pesticide in soil as a drenching……...…5 Check the seedlings for *Tuta absoluta* before transplanting…….6 Double check greenhouse net for holes .....……..7 Mass trapping with pheromone and light traps 7 days before transplanting …….....……..8 Spray a bio-pesticide or neem oil…….....…….9 Ensure pollination various methods (hand pollination) can be used…….…….10 Keep the traffic flow in the green house low……...…11 Install a tight and secure door……...…..…….12 Did not grow in a net house setting…….13	
14	Which of the following practices, if any, did you use to control *Tuta absoluta* in an open field or polyhouse setting? **(CIRCLE ALL THAT APPLY)**	None……..1 Grow tomato seedlings inside a nylon net.....2 Destroy previous crop residue after the last harvest…....3 Do not grow other host crops and remove host weeds…..4 Apply bio-pesticide in soil as a drenching……...…….…5 Check seedlings for *Tuta absoluta* before transplanting....6 Plastic mulch to help identify and reduce pupation……..7 Mass trapping with pheromone and light traps …….……8 Spray a bio-pesticide…….……...……...9 Alternate applications of botanical pesticides with bio-pesticides… ……...10 Regular field inspections to look for infestations….....11 Remove and destroy infected leaves, shoots and fruits...12 Did not grow in an open field or polyhouse setting…….....….....13	

15	How much did you spend on practices to manage *Tuta absoluta* excluding chemical pesticides?	[___|___|___|___|___|___] Nepalese rupee	
16	How many worker days did you and your family spend applying practices to manage *Tuta absoluta* excluding chemical pesticides? (Worker-day equals one day of work for one worker)	[___|___].[___|___] Number of worker-days	
17	Why did you use non-chemical practices to manage *Tuta absoluta*? **(CIRCLE ALL THAT APPLY)**	Cost less than pesticides……1 More effective than pesticides……...2 Safer for my own or my family's health……3 Better for the environment (water, soil, birds, ect.)……...4 Protects beneficial insects……..5 Market prefers or requires it……..……6 Quality of the tomato.....7	
18	Did you apply chemical pesticides to control for insect/worm pests?	No…….……..0 Yes……..1	**>SEC8**
19	Did you apply chemical pesticides for the purpose of controlling *Tuta absoluta*?	No…….……..0 Yes……..1	**>SEC8**
20	Which chemical pesticides did you apply for *Tuta absoluta* control?	Coragen……...1 Alcora……..2 Tracer/Spinosad……3 Other……..……99 Specify:_____	
21	How much did you spend on chemical pesticides for *Tuta absoluta*?	[___|___|___|___|___|___] Nepalese rupee	
22	Did you or someone in your family apply the chemical pesticides for *Tuta absoluta*?	No…….0 Yes……..……...1	**>Q24** **>Q23**
23	If yes, how many people in your family applied the chemical pesticides?	[___|___] Number of people	
24	How many worker days, on average, did each person spend applying chemical pesticides for *Tuta absoluta*? (Worker-day equals one day of work for one worker)	[___|___].[___|___] Number of days	
25	Did you pay for labor to apply chemical pesticides for *Tuta absoluta*, and if so, how much?	[___|___|___|___|___|___] Nepalese rupee	

SECTION 8: PRODUCTION, PESTS, PEST MANAGEMENT, AND CHEMCIAL PESTICIDE USE OF TOMATO CROP IN MONSOON SEASON.

No	QUESTIONS	CODES/RESPONSES	GO TO

INTERVIEWER: SAY TO THE FARMER: NOW I WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT PRODUCTION, PESTS, PEST MANAGEMENT, AND CHEMCIAL PESTICIDE USE IN YOUR TOMATO PRODUCTION DURING THE PREVIOUS MONSOON SEASON.			
In the previous monsoon season...			
1	How many **Ropani/Katha** did you plant of tomatoes? [**IF DID NOT GROW, WRITE 0]**	[___|___].[___|___]	**>IF 0, GO TO SEC 9**
2	What was your total **production** of tomatoes produced (in kilos)?	[___|___|___|___].[___|___]	
3	What was the total **value** of the tomatoes sold (in Nepalese rupees)?	[___|___|___|___|___|___] Nepalese rupee	
4	Did you produce tomatoes in a net house?	No…….0 Yes……1	**>Q8**
5	How many **Ropani/Katha** did you plant of tomatoes in net house?	[___|___].[___|___]	
6	What was your total **production** of tomatoes produced in your net house (in kilos)?	[___|___|___|___].[___|___]	
7	What was the total **value** of the tomatoes sold from those produced in a net house (in Nepalese rupees)?	[___|___|___|___|___|___] Nepalese rupee	
8	What proportion of your tomato yield did you lose due to insect and worm pests?	None……..…….0 Some, but one fourth or less……..…….....…….1 More than one fourth but less than half..…….…..2 More than one half but less than three fourths…...…3 More than three fourths……...4	
9	What proportion of your tomato yield did you lose due to disease/viruses?	None……..…….0 Some, but one fourth or less……..…….....…….1 More than one fourth but less than half..…….…..2 More than one half but less than three fourths…...…3 More than three fourths……...4	
10	Did you encounter the tomato pest *Tuta absoluta*? (**SHOW PICTURES**)	No……..…….……..0 Yes…….....…….……1	**>Q18**
11	How severe was *Tuta absoluta*?	None ……..……0 Low (some damage, yield not affected)…….……...1 Medium (some damage, yield affected)…….……...…2 High (major damage and effect on yield)…….....3	**>Q13** **>Q13** **>Q12** **>Q12**
12	What proportion of your tomato yield did you lose due to *Tuta absoluta*?	None……..…….0 Some, but one fourth or less……..…….....…….1 More than one fourth but less than half..…….…..2	

		More than one half but less than three fourths…...…3 More than three fourths……...4	
13	Which of the following practices, if any, did you use to control *Tuta absoluta* in a net house setting? **(CIRCLE ALL THAT APPLY)**	None……1 Grow seedlings inside a netted nursery……...……2 Destroy previous crop residue after last harvest…….....3 Do not grow other host crops and remove host weeds….4 Apply bio-pesticide in soil as a drenching……...…5 Check the seedlings for *Tuta absoluta* before transplanting……..6 Double check greenhouse net for holes .....……...7 Mass trapping with pheromone and light traps 7 days before transplanting …….....……..8 Spray a bio-pesticide or neem oil…….....…….9 Ensure pollination various methods (hand pollination) can be used…….……..10 Keep the traffic flow in the green house low……...…11 Install a tight and secure door……...…..……12 Did not grow in a net house setting……13	
14	Which of the following practices, if any, did you use to control *Tuta absoluta* in an open field or polyhouse setting? **(CIRCLE ALL THAT APPLY)**	None……..1 Grow tomato seedlings inside a nylon net.....2 Destroy previous crop residue after the last harvest…....3 Do not grow other host crops and remove host weeds…..4 Apply bio-pesticide in soil as a drenching……..……5 Check seedlings for *Tuta absoluta* before transplanting....6 Plastic mulch to help identify and reduce pupation…….7 Mass trapping with pheromone and light traps ……..……8 Spray a bio-pesticide…….……..……...9 Alternate applications of botanical pesticides with bio-pesticides… ……...10 Regular field inspections to look for infestations….....11 Remove and destroy infected leaves, shoots and fruits...12 Did not grow in an open field setting…….....13	
15	How much did you spend on practices to manage *Tuta absoluta* excluding chemical pesticides?	[___|___|___|___|___|___|___] Nepalese rupee	
16	How many worker days did you and your family spend applying practices to manage *Tuta absoluta* excluding chemical pesticides? (Worker-day equals one day of work for one worker)	[___|___].[___|___] Number of worker-days	
17	Why did you use non-chemical practices to manage *Tuta absoluta*? **(CIRCLE ALL THAT APPLY)**	Cost less than pesticides……1 More effective than pesticides……...2 Safer for my own or my family's health……3 Better for the environment (water, soil, birds, ect.)……...4 Protects beneficial insects……..5 Market prefers or requires it……..……6 Quality of the tomato.....7	
18	Did you apply chemical pesticides to control for insect/worm pests?	No…….……..0 Yes……..1	**>SEC9**

19	Did you apply chemical pesticides for the purpose of controlling *Tuta absoluta*?	No……..0 Yes……..1	**>SEC9**
20	Which chemical pesticides did you apply for *Tuta absoluta* control?	Coragen……..1 Alcora…….2 Tracer/Spinosad……3 Does not know name.....4 Other……..……99 Specify:_____	
21	How much did you spend on chemical pesticides for *Tuta absoluta*?	[___|___|___|___|___|___] Nepalese rupee	
22	Did you or someone in your family apply the chemical pesticides for *Tuta absoluta*?	No…….0 Yes……..……...1	**>Q24** **>Q23**
23	If yes, how many people in your family applied the chemical pesticides?	[___|___] Number of people	
24	How many worker days, on average, did each person spend ap plying chemical pesticides for *Tuta absoluta*? (Worker-day equals one day of work for one worker)	[___|___].[___|___] Number of days	
25	Did you pay for labor to apply chemical pesticides for *Tuta absoluta*, and if so, how much?	[___|___|___|___|___|___] Nepalese rupee	

SECTION 9: ADDITIONAL INFORMATION ON TOMATO CONSUMPTION AND PRODUCTION

No	QUESTIONS	CODES/RESPONSES	GO TO
INTERVIEWER: SAY TO THE FARMER: NOW I WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT YOUR OVERALL TOMATO CONSUMPTION AND PRODUCTION.			
1	What proportion of your tomato production did you consume in your household?	None……..0 Some, but less than half……...…1 Half or more…….2	
2	If you sold tomatoes, to whom did you sell them to? **(CIRCLE ALL THAT APPLY)**	Local trader……...1 Non-local trader……2 Cooperative or Collection Center..……...3 Sold it myself (or family did) in market……...4 Neighbors……..5 Other (Specify)_____.....99	
3	What proportion of your family's total income is from selling tomatoes?	None……..…..……0 Some, but one fourth or less……..……....…….1 More than one fourth but less than half...…….…..2 More than one half but less than three fourths…...…3 More than three fourths……...4	
4	What is your source of tomato seeds?	Private seed seller/agro-vet…….……1 Government seed source…….…..2	

	(CIRCLE ALL THAT APPLY)	Self (saved from previous crop)……3 Neighbor/relative/friend……..……..4 CBF.....5 Other(Specify)_____.....99	

SECTION 10: IPM TRAINING

No	QUESTIONS	CODES/RESPONSES	GO TO
INTERVIEWER: SAY TO THE FARMER: NOW I WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT THE TYPE OF TRAINING YOU HAVE RECEIVED ON IPM AND PESTICIDE USE.			
1	Have you received any training related to IPM?	No……..……..……0 Yes……..……...1	**>SEC11** **>Q2**
2	If, yes have you received IPM training to manage *Tuta absoluta*?	No…….0 Yes……1	**>SEC11** **>Q3**
3	From whom did you receive training? [**READ LIST BELOW]**		
a	……Agriculture Extension Officer (GoN)?	No……..……..0 Yes……..……...1	
b	……Agro-vet?	No……..……..……0 Yes……..……...1	
c	……Community Business Facilitator (CBF)	No……..……..……0 Yes……..……...1	
d	……NGO	No……..……..……0 Yes……..……...1	
e	……Other	No……..……..……0 Yes……..……...1	**>Q3.f**
f	Specify the other	_____	

SECTION 11: ADDITIONAL PRODUCTION METHODS

No	QUESTIONS	CODES/RESPONSES	GO TO
INTERVIEWER: SAY TO THE FARMER: NOW I WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT ADDITIONAL PRODUCTION METHODS USED IN VARIOUS VEGETABLES CROPS.			
1	Did you use Trichoderma on a vegetable crop in the last 12 months?	No……..……..……0 Yes……..……...1	**>Q9** **>Q2**
2	If yes, where did you obtain the Trichoderma?	Agro-vet……..…1 Neighbor……..2 Relative……3 CBF……...4	

		Other……99 Specify: _____	
3	Which type of Trichoderma did you use?	Liquid.....1 Powder.....2	
4	What brand of Trichoderma did you use?	Biocide Trivi……..……..……1 Sanjeevi…….…….....…2 Biocure-F…….…….....…..……3 Prarmva Trichoderma…….…….....……4 Local Produce (Cooperatives/Resource Center).....5 Does not know.....6 Other (Specify):_____...99	
5	Did you use Trichoderma on chili plants?	No……..……..……..…0 Yes…….……...1	**>Q6**
a	Which method did you use to apply the Trichoderma to the chili plants?	Mixed in soil before planting/drenching in soil……1 Mixed in compost/Farm Yard Manure (FYM) and use during transplanting.....2 Added to drip irrigation during growing season……3 Through foliar spray during growing season ……4 Other (Specify):_____...99	
6	Did you use Trichoderma on eggplant plants?	No……..……..……..…0 Yes…….……...1	**>Q7**
a	Which method did you use to apply the Trichoderma to the eggplant plants?	Mixed in soil before planting/drenching in soil……1 Mixed in compost/Farm Yard Manure (FYM) and use during transplanting.....2 Added to drip irrigation during growing season……3 Through foliar spray during growing season ……4 Other (Specify):_____...99	
7	Did you use Trichoderma on tomato plants?	No……..……..……..…0 Yes…….……...1	**>Q8**
a	Which method did you use to apply the Trichoderma to the tomato plants?	Mixed in soil before planting/drenching in soil……1 Mixed in compost/Farm Yard Manure (FYM) and use during transplanting.....2 Added to drip irrigation during growing season……3 Through foliar spray during growing season ……4 Other (Specify):_____...99	
8	Did you use Trichoderma on cauliflower plants?	No……..……..……..…0 Yes…….……...1	**>Q9**
a	Which method did you use to apply the Trichoderma to the cauliflower plants?	Mixed in soil before planting/drenching in soil……1 Mixed in compost/Farm Yard Manure (FYM) and use during transplanting.....2 Added to drip irrigation during growing season……3 Through foliar spray during growing season ……4 Other (Specify):_____...99	
9	Did you use coconut pith in trays to raise seedlings?	No……0 Yes……...1	**>STOP**

10	What type of coconut pith did you use?	Without nutrients.....0 With nutrients.....1	
11	Do you mix Trichoderma with coconut pith in seed trays?	No……0 Yes……...1	
12	On which crops did you use coconut pith in trays to raise seedlings? **READ LIST BELOW**		
a	…Chili	No……..……..……0 Yes……..……..……...1	
a	…Eggplant	No……..……..……0 Yes……..……..……...1	
c	…Tomatoes	No……..……..……0 Yes……..……..……...1	
d	…Cauliflower	No……..……..……0 Yes……..……..……...1	

Thank you for your time!

Appendix C: Stata Results

C.1 Adoption Regression with Binary Adoption Dependent Variable

eprobit adopt age i.female educ exper i.migrant fmsz houselab landt distag i.memb i.cbf i.media i.agcon i.personal i.sev, endogenous(train = villtrain, probit) endogenous (traintuta = villtraintuta, probit)

Extended probit regression — Number of obs = 400
Wald chi2(17) = 43.08
Log likelihood = -514.87729 — Prob > chi2 = 0.0005

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
adopt						
age	.005096	.0085909	0.59	0.553	-.0117419	.0219339
2.female	.0188706	.2107359	0.09	0.929	-.3941642	.4319054
educ	.0099033	.0210112	0.47	0.637	-.0312779	.0510845
exper	.0045107	.0195561	0.23	0.818	-.0338184	.0428399
1.migrant	.0790897	.1738574	0.45	0.649	-.2616647	.419844
fmsz	.0085245	.0118989	0.72	0.474	-.014797	.031846
houselab	.0351006	.0416785	0.84	0.400	-.0465879	.116789
landt	.170206	.0852306	2.00	0.046	.0031571	.3372549
distag	-.0694976	.0172301	-4.03	0.000	-.103268	-.0357272
1.memb	.4795729	.2909599	1.65	0.099	-.0906979	1.049844
1.cbf	.0939763	.1876134	0.50	0.616	-.2737391	.4616918
1.media	-.183012	.2051113	-0.89	0.372	-.5850228	.2189988
1.agcon	-.1843348	.2543211	-0.72	0.469	-.682795	.3141253
1.personal	-.4895717	.4073442	-1.20	0.229	-1.287952	.3088084
1.sev	.4248207	.1737374	2.45	0.014	.0843017	.7653397
1.train	.2362977	.3023454	0.78	0.434	-.3562884	.8288838
1.traintuta	.9312313	.439126	2.12	0.034	.0705602	1.791902
_cons	.4376988	.7986153	0.55	0.584	-1.127558	2.002956

C.2 Average Marginal Effects of Adoption Regression with Binary Adoption Dependent Variable

margins, dydx(age i.female educ exper i.migrant fmsz houselab landt distag i.memb i.cbf i.media i.agcon i.personal train traintuta i.sev)

Average marginal effects Number of obs = 400
Model VCE : OIM

	dy/dx	Delta-method Std. Err.	z	P>|z|	[95% Conf.	Interval]
age	.0013086	.0022065	0.59	0.553	-.003016	.0056332
2.female	.0048598	.0544388	0.09	0.929	-.1018383	.1115579
educ	.0025431	.005395	0.47	0.637	-.0080308	.0131171
exper	.0011584	.0050199	0.23	0.818	-.0086805	.0109973
1.migrant	.0200746	.0435994	0.46	0.645	-.0653786	.1055278
fmsz	.0430334	.060082	0.72	0.474	-.0747252	.1607921
houselab	.009014	.0106849	0.84	0.399	-.0119279	.0299559
landt	.8591837	.4220506	2.04	0.042	.0319797	1.686388
distag	-.0178475	.0041246	-4.33	0.000	-.0259316	-.0097634
1.memb	.1392627	.0924698	1.51	0.132	-.0419748	.3205001
1.cbf	.0241729	.0479907	0.50	0.614	-.0698872	.118233
1.media	-.0450421	.0481733	-0.94	0.350	-.13946	.0493757
1.agcon	-.0449236	.0586101	-0.77	0.443	-.1597973	.0699501
1.personal	-.1061617	.0712682	-1.49	0.136	-.2458448	.0335215
1.sev	.117515	.0501976	2.34	0.019	.0191296	.2159004
1.train	.0139748	.0796778	0.18	0.861	-.1421908	.1701405
1.traintuta	.1240813	.0875734	1.42	0.157	-.0475593	.2957219

Note: dy/dx for factor levels is the discrete change from the base level.

C.3 Adoption Regression with Tri-Leveled Adoption Dependent Variable

cmp (adopttri = age female educ exper migrant fmsz houselab landt distag memb cbf media agcon personal train traintuta sev)(train = villtrain age female educ exper migrant fmsz houselab landt distag memb cbf media personal sev)(traintuta = villtraintuta age female educ exper migrant fmsz houselab landt distag memb cbf media personal sev), indicators ($cmp_oprobit, $cmp_probit, $cmp_probit)

Mixed-process regression — Number of obs = 400
LR chi2(47) = 285.71
Log likelihood = -682.655 — Prob > chi2 = 0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
adopttri						
age	.0037033	.0068891	0.54	0.591	-.0097991	.0172057
female	-.1826929	.1714344	-1.07	0.287	-.518698	.1533123
educ	.0191953	.016927	1.13	0.257	-.0139811	.0523717
exper	.0115714	.0166329	0.70	0.487	-.0210286	.0441713
migrant	.1314122	.1383346	0.95	0.342	-.1397187	.402543
fmsz	-.0790352	.1830328	-0.43	0.666	-.437773	.2797025
houselab	-.0080969	.0318714	-0.25	0.799	-.0705637	.0543699
landt	3.455879	1.315007	2.63	0.009	.8785135	6.033245
distag	-.0713763	.014263	-5.00	0.000	-.0993312	-.0434213
memb	.2239288	.2538799	0.88	0.378	-.2736666	.7215242
cbf	.1804327	.1493797	1.21	0.227	-.1123461	.4732115
media	-.1868643	.1625262	-1.15	0.250	-.5054097	.1316811
agcon	-.0866719	.2007329	-0.43	0.666	-.4801011	.3067573
personal	-.4264685	.2922463	-1.46	0.144	-.9992608	.1463237
train	.5224296	.245306	2.13	0.033	.0416387	1.00322
traintuta	.6690517	.2940431	2.28	0.023	.0927379	1.245365
sev	.4045645	.1463223	2.76	0.006	.1177781	.6913509

train						
villtrain	.2508676	.0357657	7.01	0.000	.1807682	.320967
age	.0063505	.0080208	0.79	0.429	-.0093699	.0220709
female	.4975833	.1994663	2.49	0.013	.1066365	.8885301
educ	.0201039	.0208514	0.96	0.335	-.020764	.0609718
exper	.0499648	.0187608	2.66	0.008	.0131943	.0867352
migrant	-.2044057	.160864	-1.27	0.204	-.5196933	.1108819
fmsz	-.0658363	.2236202	-0.29	0.768	-.5041238	.3724512
houselab	-.0039773	.0400775	-0.10	0.921	-.0825277	.0745731
landt	1.60276	1.038388	1.54	0.123	-.432443	3.637962
distag	-.0074438	.0162724	-0.46	0.647	-.0393371	.0244495
memb	.1143428	.293688	0.39	0.697	-.4612751	.6899606
cbf	.1647754	.1544795	1.07	0.286	-.1379988	.4675496
media	.1228825	.1983862	0.62	0.536	-.2659472	.5117123
personal	-.4821907	.309353	-1.56	0.119	-1.088511	.12413
sev	.1818714	.1723964	1.05	0.291	-.1560192	.5197621
_cons	-2.556407	.8473102	-3.02	0.003	-4.217105	-.8957096
traintuta						
villtraintuta	.3592902	.0490534	7.32	0.000	.2631474	.4554331
age	.0217397	.0101417	2.14	0.032	.0018623	.0416171
female	.2304676	.2399616	0.96	0.337	-.2398485	.7007837
educ	.016301	.0247824	0.66	0.511	-.0322716	.0648736
exper	.0257654	.018887	1.36	0.173	-.0112524	.0627832
migrant	-.0617966	.1889173	-0.33	0.744	-.4320677	.3084745
fmsz	-.0412536	.2921721	-0.14	0.888	-.6139004	.5313931
houselab	.0335034	.0510644	0.66	0.512	-.066581	.1335877
landt	-.8458969	1.267971	-0.67	0.505	-3.331074	1.63928
distag	-.0105826	.0206456	-0.51	0.608	-.0510473	.0298821
memb	1.159499	.502039	2.31	0.021	.175521	2.143478
cbf	.1038088	.2141124	0.48	0.628	-.3158439	.5234614
media	-.0793898	.2430322	-0.33	0.744	-.5557241	.3969444
personal	.1532022	.3887565	0.39	0.694	-.6087465	.9151509
sev	.2882603	.2210201	1.30	0.192	-.1449311	.7214518
_cons	-4.864499	1.064046	-4.57	0.000	-6.949991	-2.779006

C.4 Average Marginal Effects of Adoption Regression with Tri-Leveled Adoption Dependent Variable: Non/Simple Adopters

margins, dydx(*) predict(eq(#1) outcome(#1)pr)

```
Average marginal effects                        Number of obs     =        400
Model VCE    : OIM

Expression   : Pr(adopttri=1), predict(eq(#1) outcome(#1)pr)
dy/dx w.r.t. : age female educ exper migrant fmsz houselab landt distag memb
               cbf media agcon personal train traintuta sev villtrain
               villtraintuta
```

	dy/dx	Delta-method Std. Err.	z	P>|z|	[95% Conf.	Interval]
age	-.0009444	.0017522	-0.54	0.590	-.0043786	.0024898
female	.0465875	.0438437	1.06	0.288	-.0393446	.1325195
educ	-.0048949	.0043016	-1.14	0.255	-.0133259	.0035361
exper	-.0029507	.0042274	-0.70	0.485	-.0112363	.0053348
migrant	-.0335107	.0352879	-0.95	0.342	-.1026737	.0356524
fmsz	.0201543	.0465909	0.43	0.665	-.0711621	.1114707
houselab	.0020647	.0081287	0.25	0.799	-.0138673	.0179968
landt	-.8812639	.3302151	-2.67	0.008	-1.528474	-.2340542
distag	.0182012	.0034269	5.31	0.000	.0114847	.0249178
memb	-.0571028	.0644774	-0.89	0.376	-.1834761	.0692706
cbf	-.0460111	.0375461	-1.23	0.220	-.1196001	.0275779
media	.0476512	.0414221	1.15	0.250	-.0335346	.128837
agcon	.0221017	.0511899	0.43	0.666	-.0782287	.1224321
personal	.1087513	.0745001	1.46	0.144	-.0372662	.2547688
train	-.1332218	.0623579	-2.14	0.033	-.255441	-.0110025
traintuta	-.170611	.0783031	-2.18	0.029	-.3240822	-.0171399
sev	-.1031657	.0363097	-2.84	0.004	-.1743314	-.0319999
villtrain	0	(omitted)				
villtraintuta	0	(omitted)				

C.5 Average Marginal Effects of Adoption Regression with Tri-Leveled Adoption Dependent Variable: Adopters of One Complex Practice

margins, dydx(*) predict(eq(#1) outcome(#2)pr)

```
Average marginal effects                        Number of obs     =        400
Model VCE    : OIM

Expression   : Pr(adopttri=2), predict(eq(#1) outcome(#2)pr)
dy/dx w.r.t. : age female educ exper migrant fmsz houselab landt distag memb
               cbf media agcon personal train traintuta sev villtrain
               villtraintuta
```

	dy/dx	Delta-method Std. Err.	z	P>|z|	[95% Conf.	Interval]
age	-.0002887	.0005482	-0.53	0.598	-.0013631	.0007858
female	.01424	.013258	1.07	0.283	-.0117451	.0402251
educ	-.0014962	.0013774	-1.09	0.277	-.0041958	.0012035
exper	-.0009019	.0013437	-0.67	0.502	-.0035355	.0017317
migrant	-.0102429	.0108526	-0.94	0.345	-.0315135	.0110277
fmsz	.0061604	.0145086	0.42	0.671	-.022276	.0345968
houselab	.0006311	.0024849	0.25	0.800	-.0042392	.0055014
landt	-.2693684	.124047	-2.17	0.030	-.5124961	-.0262408
distag	.0055634	.0018016	3.09	0.002	.0020323	.0090945
memb	-.0174541	.0204851	-0.85	0.394	-.0576042	.0226959
cbf	-.0140638	.0130038	-1.08	0.279	-.0395507	.0114231
media	.0145651	.0129281	1.13	0.260	-.0107735	.0399038
agcon	.0067556	.0156382	0.43	0.666	-.0238947	.037406
personal	.0332411	.0238096	1.40	0.163	-.0134248	.079907
train	-.0407208	.0186845	-2.18	0.029	-.0773418	-.0040997
traintuta	-.0521492	.0184806	-2.82	0.005	-.0883705	-.0159279
sev	-.0315338	.0144711	-2.18	0.029	-.0598965	-.003171
villtrain	0	(omitted)				
villtraintuta	0	(omitted)				

C.6 Average Marginal Effects of Adoption Regression with Tri-Leveled Adoption Dependent Variable: Adopters of Two or More Complex Practice

margins, dydx(*) predict(eq(#1) outcome(#3)pr)

Average marginal effects — Number of obs = 400
Model VCE : **OIM**

Expression : **Pr(adopttri=3), predict(eq(#1) outcome(#3)pr)**
dy/dx w.r.t. : **age female educ exper migrant fmsz houselab landt distag memb cbf media agcon personal train traintuta sev villtrain villtraintuta**

	dy/dx	Delta-method Std. Err.	z	P>|z|	[95% Conf.	Interval]
age	.001233	.0022962	0.54	0.591	-.0032675	.0057335
female	-.0608275	.0566834	-1.07	0.283	-.171925	.05027
educ	.0063911	.0056336	1.13	0.257	-.0046507	.0174328
exper	.0038527	.0055547	0.69	0.488	-.0070343	.0147397
migrant	.0437536	.0458727	0.95	0.340	-.0461552	.1336624
fmsz	-.0263147	.0610284	-0.43	0.666	-.1459282	.0932987
houselab	-.0026959	.0106092	-0.25	0.799	-.0234896	.0180978
landt	1.150633	.4370926	2.63	0.008	.2939469	2.007318
distag	-.0237647	.0046823	-5.08	0.000	-.0329418	-.0145875
memb	.0745569	.0845518	0.88	0.378	-.0911616	.2402754
cbf	.0600749	.0501641	1.20	0.231	-.0382449	.1583947
media	-.0622164	.0538918	-1.15	0.248	-.1678423	.0434096
agcon	-.0288573	.0667479	-0.43	0.665	-.1596808	.1019661
personal	-.1419924	.0969982	-1.46	0.143	-.3321053	.0481205
train	.1739426	.0786045	2.21	0.027	.0198806	.3280045
traintuta	.2227603	.0939429	2.37	0.018	.0386356	.406885
sev	.1346995	.048808	2.76	0.006	.0390376	.2303613
villtrain	0	(omitted)				
villtraintuta	0	(omitted)				

C.7 Adoption Regression with Continuous Adoption Dependent Variable: Continuous Count of Complex Practices

ivregress 2sls adoptcontcom age female educ exper migrant fmsz houselab landt distag memb cbf media agcon personal sev (train traintuta = villtrain villtraintuta)

```
Instrumental variables (2SLS) regression          Number of obs   =        400
                                                  Wald chi2(17)   =      49.79
                                                  Prob > chi2     =     0.0000
                                                  R-squared       =          .
                                                  Root MSE        =     .82123
```

adoptcontcom	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
train	.3598192	.2648454	1.36	0.174	-.1592683	.8789067
traintuta	.7726352	.3110971	2.48	0.013	.1628961	1.382374
age	-.002743	.0048613	-0.56	0.573	-.0122711	.006785
female	-.0645648	.119755	-0.54	0.590	-.2992804	.1701507
educ	.0063619	.0117776	0.54	0.589	-.0167217	.0294456
exper	-.011296	.0112933	-1.00	0.317	-.0334306	.0108385
migrant	.075261	.098793	0.76	0.446	-.1183698	.2688917
fmsz	-.1462043	.1346383	-1.09	0.278	-.4100904	.1176818
houselab	.0471833	.0230674	2.05	0.041	.0019722	.0923945
landt	.344123	.4774726	0.72	0.471	-.5917061	1.279952
distag	-.0286996	.0091946	-3.12	0.002	-.0467206	-.0106786
memb	-.0117108	.180546	-0.06	0.948	-.3655744	.3421528
cbf	-.0148958	.1016664	-0.15	0.884	-.2141582	.1843666
media	-.153069	.1158572	-1.32	0.186	-.380145	.074007
agcon	-.1831787	.169663	-1.08	0.280	-.515712	.1493546
personal	-.2465329	.1864035	-1.32	0.186	-.6118771	.1188114
sev	-.0937734	.1019214	-0.92	0.358	-.2935356	.1059889
_cons	1.876951	.5127542	3.66	0.000	.8719713	2.881931

```
Instrumented:  train traintuta
Instruments:   age female educ exper migrant fmsz houselab landt distag memb
               cbf media agcon personal sev villtrain villtraintuta
```

C.8 Adoption Regression with Continuous Adoption Dependent Variable: Continuous Count of All Practices

ivregress 2sls adoptcont age female educ exper migrant fmsz houselab landt distag memb cbf media agcon personal sev (train traintuta = villtrain villtraintuta)

Instrumental variables (2SLS) regression

Number of obs	=	400
Wald chi2(17)	=	81.00
Prob > chi2	=	0.0000
R-squared	=	0.1041
Root MSE	=	1.5449

adoptcont	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
train	.72546	.4982329	1.46	0.145	-.2510585	1.701979
traintuta	1.58884	.5852425	2.71	0.007	.4417858	2.735894
age	-.0029141	.0091453	-0.32	0.750	-.0208385	.0150103
female	-.2574651	.2252857	-1.14	0.253	-.699017	.1840868
educ	.0007194	.0221563	0.03	0.974	-.0427061	.0441448
exper	.012746	.0212453	0.60	0.549	-.028894	.0543859
migrant	.1443438	.1858515	0.78	0.437	-.2199185	.508606
fmsz	.1392204	.2532843	0.55	0.583	-.3572078	.6356486
houselab	-.02994	.0433948	-0.69	0.490	-.1149922	.0551123
landt	2.094258	.8982317	2.33	0.020	.3337563	3.85476
distag	-.0365158	.017297	-2.11	0.035	-.0704173	-.0026143
memb	-.3446874	.3396469	-1.01	0.310	-1.010383	.3210083
cbf	-.0411698	.1912569	-0.22	0.830	-.4160265	.3336869
media	-.0021985	.2179531	-0.01	0.992	-.4293786	.4249817
agcon	.1420732	.3191736	0.45	0.656	-.4834955	.767642
personal	.1363828	.3506663	0.39	0.697	-.5509106	.8236761
sev	.7625138	.1917367	3.98	0.000	.3867168	1.138311
_cons	3.765716	.9646042	3.90	0.000	1.875127	5.656306

Instrumented: train traintuta
Instruments: age female educ exper migrant fmsz houselab landt distag memb cbf media agcon personal sev villtrain villtraintuta

C.9 Correlation of Adoption Model Variables

correlate adopt age female educ exper migrant fmsz houselab landt distag memb cbf media agcon personal sev train traintuta

(obs=400)

	adopt	age	female	educ	exper	migrant	fmsz	houselab	landt
adopt	1.0000								
age	0.0915	1.0000							
female	-0.0021	-0.3086	1.0000						
educ	0.0072	-0.4458	-0.1694	1.0000					
exper	0.0156	0.1363	-0.2685	-0.0408	1.0000				
migrant	0.0288	0.0616	0.0873	-0.0023	-0.0269	1.0000			
fmsz	0.0460	0.1829	-0.1069	0.0797	0.0997	0.1392	1.0000		
houselab	0.0715	0.2259	-0.1353	-0.1578	0.1587	0.1959	0.2541	1.0000	
landt	0.0580	-0.0605	-0.2908	0.1356	0.1214	-0.0733	-0.0077	0.0295	1.0000
distag	-0.2058	-0.2226	-0.1312	-0.0052	0.2801	-0.0909	-0.0591	-0.0440	0.1775
memb	0.0595	-0.0578	-0.0135	0.0668	0.1587	-0.0311	0.1423	-0.0312	0.0109
cbf	0.0704	0.0537	0.0023	-0.0461	0.0721	0.0087	0.0139	-0.0649	0.0234
media	-0.0076	-0.0503	-0.0581	0.1805	0.1077	0.0438	0.2091	0.0878	0.0433
agcon	0.0598	0.0289	-0.0602	0.0213	0.0815	0.0436	0.1736	0.0890	0.1135
personal	-0.0770	-0.0176	0.0300	-0.0266	0.0458	0.0644	0.1154	-0.0402	-0.0423
sev	0.1049	-0.0440	0.1019	-0.1118	-0.0342	-0.0118	-0.1103	0.0750	0.0486
train	0.1056	-0.0221	0.0718	0.0105	0.1360	-0.1056	-0.0735	-0.0330	0.0799
traintuta	0.1832	0.1203	0.0153	-0.0600	0.1203	0.0123	0.0063	0.0482	0.0017

	distag	memb	cbf	media	agcon	personal	sev	train	traint~a
distag	1.0000								
memb	0.1323	1.0000							
cbf	0.1260	0.0392	1.0000						
media	-0.0363	0.1140	-0.0023	1.0000					
agcon	0.0322	-0.0077	0.3458	0.1181	1.0000				
personal	0.1487	0.1091	0.0525	-0.0319	0.0041	1.0000			
sev	0.0705	-0.0294	-0.0028	-0.0195	0.1062	-0.0382	1.0000		
train	0.0014	0.0179	0.2010	0.0923	0.3177	-0.0654	0.0667	1.0000	
traintuta	-0.0037	0.1053	0.2725	0.0036	0.1875	0.0416	0.0876	0.3967	1.0000

C.10 Pesticide Use Regression with Continuous Dependent Variable

ivregress 2sls chemcost age female educ exper fmsz houselab landt cbf media agcon personal sev hiredlabor (adopt = distag traintuta)

Instrumental variables (2SLS) regression

Number of obs	400
Wald chi2(14)	176.30
Prob > chi2	0.0000
R-squared	0.2025
Root MSE	2086.6

chemcost	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
adopt	1840.434	1015.147	1.81	0.070	-149.2175	3830.085
age	-46.79632	12.32516	-3.80	0.000	-70.95319	-22.63945
female	-707.9633	289.5688	-2.44	0.014	-1275.508	-140.4189
educ	-95.92863	30.86724	-3.11	0.002	-156.4273	-35.42995
exper	3.449265	25.62209	0.13	0.893	-46.76911	53.66764
fmsz	3.81215	16.66278	0.23	0.819	-28.8463	36.4706
houselab	9.994248	58.18255	0.17	0.864	-104.0415	124.03
landt	573.1332	65.67792	8.73	0.000	444.4068	701.8595
cbf	-252.5053	235.7057	-1.07	0.284	-714.48	209.4694
media	-378.4697	287.1849	-1.32	0.188	-941.3419	184.4024
agcon	220.0437	349.7827	0.63	0.529	-465.5178	905.6053
personal	-426.4469	474.4674	-0.90	0.369	-1356.386	503.4922
sev	569.486	274.0916	2.08	0.038	32.27647	1106.696
hiredlabor	1232.19	1168.072	1.05	0.291	-1057.188	3521.569
_cons	3046.746	1166.709	2.61	0.009	760.0376	5333.454

Instrumented: adopt
Instruments: age female educ exper fmsz houselab landt cbf media agcon personal sev hiredlabor distag traintuta

C.11 Correlation of Pesticide Use Model Variables

correlate chemcost age female educ exper fmsz houselab landt cbf media agcon personal sev hiredlabor adopt distag traintuta

(obs=400)

	chemcost	age	female	educ	exper	fmsz	houselab	landt	cbf	media	agcon	personal	sev	hiredl~r	adopt
chemcost	1.0000														
age	-0.1151	1.0000													
female	-0.1576	-0.3086	1.0000												
educ	-0.0085	-0.4458	-0.1694	1.0000											
exper	0.0654	0.1363	-0.2685	-0.0408	1.0000										
fmsz	-0.0392	0.1829	-0.1069	0.0797	0.0997	1.0000									
houselab	0.0503	0.2259	-0.1353	-0.1578	0.1587	0.2541	1.0000								
landt	0.5277	-0.0605	-0.2908	0.1356	0.1214	-0.0077	0.0295	1.0000							
cbf	-0.0222	0.0537	0.0023	-0.0461	0.0721	0.0139	-0.0649	0.0234	1.0000						
media	-0.0486	-0.0503	-0.0581	0.1805	0.1077	0.2092	0.0878	0.0434	-0.0023	1.0000					
agcon	0.0896	0.0289	-0.0602	0.0213	0.0815	0.1736	0.0890	0.1135	0.3458	0.1181	1.0000				
personal	-0.0894	-0.0176	0.0300	-0.0266	0.0458	0.1154	-0.0402	-0.0423	0.0525	-0.0319	0.0041	1.0000			
sev	0.1826	-0.0440	0.1019	-0.1118	-0.0342	-0.1104	0.0750	0.0486	-0.0028	-0.0195	0.1062	-0.0382	1.0000		
hiredlabor	0.2432	-0.0552	0.0094	0.0008	-0.0337	0.0726	-0.0433	0.3406	-0.1000	0.0471	0.0380	-0.0831	-0.0024	1.0000	
adopt	-0.0307	0.0915	-0.0021	0.0072	0.0156	0.0460	0.0715	0.0580	0.0704	-0.0076	0.0598	-0.0770	0.1049	0.0526	1.0000
distag	0.0571	-0.2226	-0.1312	-0.0052	0.2801	-0.0591	-0.0440	0.1775	0.1260	-0.0363	0.0322	0.1487	0.0705	0.0139	-0.2058
traintuta	-0.0066	0.1203	0.0153	-0.0600	0.1203	0.0063	0.0482	0.0017	0.2725	0.0036	0.1875	0.0416	0.0876	-0.0499	0.1832

	distag	traint~a
distag	1.0000	
traintuta	-0.0037	1.0000