ADDIS ABABA UNIVERSITY
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THE DETERMINANTS OF AGRICULTURAL TECHNOLOGY ADOPTION AND ITS' IMPACT ON *TEFF* PRODUCTIVITY IN THE CASE OF AMHARA AND OROMIA NATIONAL REGIONAL STATE

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The Determinants of Agricultural Technology Adoption and Its' Impact On *Teff* Productivity in the Case of Amhara and Oromia National Regional State

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This is to certify that the thesis prepared by Etsehiwot Semreab, entitled: The Determinants of Agricultural Technology Adoption and its' Impact on *Teff* Productivity in case of Amhara and Oromia National Regional State and submitted in partial fulfillment of the requirements for the degree of Master of Science (Economic Policy Analysis) compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

Enhancing the productivity of agriculture sector plays a vital role for country like Ethiopia where reducing poverty and sustaining food security is government's main agenda. In order to enhance the productivity of agriculture sector, Ethiopian government promotes adoption of multiple agriculture technology. However, in most of the rural areas of Ethiopian farmers adopt single and mix of technology rather than adopting all available practices. As a result, understanding the determinant of adoption of multiple agricultural technology and its impacts on productivity is essential to design appropriate policy options for the wider adoption process. Thus, this study analyzes farmer's choice of single and combination choice of agricultural technologies (i.e. improved teff variety, fertilizer and row planting) and evaluates the impact of these technologies on the productivity of teff. The study used EDRIs' teff value chain data which was collected from 1200 households in Amhara and Oromia regions during 2012. Multinomial logit and endogenous switching regression models were employed to achieve the above objectives. The result of endogenus swiching model reveals that adoption of agricultural technologies has a positive and significant impact on productivity of tef. Moreover the result of the study also shows that full technology adopters' are more productive than other alternative technology adopters. According to the multinomial logit result, technology adoption is positively related with sex, education, soil fertility, contact with an extension and DAs' visit. But adoption of agriculture technologies have negative and significant relation with age, distance to main road, distance to the input and out market, parcel ownership and farm size. The study recommends that the government should enhance DAs' and extension service, increase the access of infrastructure, and encourage women by giving especial service like credit access, extension service and community discussion to widespread the adoption of agricultural technologies.

Key words: Agricultural technologies, Multinomial logit, Multinomial endogenous swiching regression, Ethiopia

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Acronym

ADLIA- agricultural Development-Led Industrialization

ARS- Amhara Regional State

ATA- Agricultural Transformation Agency

ATT- Average Treatment Effect on Treated

ATU- Average Treatment Effect on Untreated

EPRDF- Ethiopian People's Revolutionary Democratic Front

$F_0I_0R_0$ – non adopters

$F_1I_0R_0$ – fertilizer adopters without improved seed and row planting

$F_1I_1R_0$ – fertilizer and improved seed adopters without row planting

$F_1I_0R_1$ – fertilizer and row planting adopter without improved seed

$F_1I_1R_1$ – fertilizer, improve seed and row planting adopters

FIR- fertilizer, improved seed and row planting

GDP- gross domestic product

GTP I - Growth and Transformation Plan I

GTP II -Growth and Transformation Plan II

HYV – high yield verity

IIA- Independence of Irrelevant Alternatives

PASDEP- Plan for Accelerated and Sustainable Development to End Poverty

MESR - Multinomial Endogenous switching regression

MPP- Minimum Package Program

MNLM- Multinomial Logit Model

MNPM - Multinomial Probit Model

MoA -Ministry of agriculture

NARS - National Agricultural Research System

SAPs - Sustainable Agricultural Practices Regional State

SDPRP - Sustainable Development and Poverty Reduction Program

SSA- Sub-Saharan Africa

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CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Ethiopian economy is depends heavily on agriculture as the main source of employment, income and food security for a vast majority of its population. In 2016, the agriculture sector contributed 37.2 percent to the GDP and 78 percent of export income while creating an employment opportunity for 75 percent male and 59 percent female population in the country (World Bank, 2016). Beside to this it plays vital role in food security and in raising the income of 12 million farmers in the country. In this regard, the sector has been contributing in reducing poverty by 20.6 percent between the years 2000 (44 percent) to 2015 (23.4 percent) (ATA, 2016/2017). Although the Ethiopian government has given serious attention to this sector, as the major means of poverty reduction and overall economic transformation, the productivity of this sector has remained low for a long time because of poor resource endowments and minimal use of inputs (i.e. Fertilizer, improved seeds, and irrigation) (OECD-FAO,2016). Moreover, continuing environmental degradation, high population growth, and low levels of investment in agricultural infrastructure also aggravated the resource limitations of agriculture in the region (Tilahun and Amsalu, 2014).

Starting from the imperial Haile Selasie period, Ethiopia has been designing and implementing different policies and strategies to enhance the productivity of the agricultural sector through improving the rate of agricultural technology adoption.

During imperial Haile Selasie period the Ethiopia government had introduced the Minimum Package Program (MPP) to bring about economic and social changes. This program is designed to bring rural development by facilitating credit access to purchase agricultural technologies (like fertilizers, improved seeds and pesticides); innovative extension services; the establishment of cooperatives and the provision of infrastructure, (mainly water supply and all-weather roads). In addition to this, the government was encouraging large scale commercial farms by giving incentives to investors to import fertilizers, pesticides, tractors, duties free fuel and combiners until 1973 to encouraged the rapid expansion of large-scale commercial farming. (Adams, 1970).

After the downfall of the imperial regime, the Socialist government (DERG) took over power and encapsulated in the Ten-Year Perspective Plan (1984/85-1993/94). During this regime the focus of the sector shifted towards the state and cooperative farms to addressing food security (Mengistu

et al., 2017). During this regime the government subsidizes the state and cooperative farm by selling agricultural technologies at lower prices (*Ibid*).

The current government led by the Ethiopian People's Revolutionary Democratic Front (EPRDF), also gave especial attention to agriculture by putting in place an overarching framework popularly known as "Agricultural Development-Led Industrialization (ADLI)" policy which sets out agriculture as a primary stimulus to generate increased output, employment and income for the people. It further accentuates that agriculture will serve as a springboard for the development of other economic sectors of the country (Keeley and Scoones, 2000). Under the broader framework of ADLI various plans and strategies were prepared and implemented. These include Sustainable Development and Poverty Reduction Program (SDPRP (2002/03- 2004/05)); Plan for Accelerated and Sustainable Development to End Poverty (PASDEP (2005/06-2009/10)); Growth and Transformation Plan I (GTP I (2010/11-2014/15)) and Growth and Transformation Plan II (GTP II (2015/16- 2019-20)). These plans main objectives were to increase the sector's productivity through promoting agricultural technologies and their enabling factors (i.e. Fertilizers, improved seeds, and better management practices, credit access) to reduce food insecurity, poverty and unemployment (Chipeta, 2015).

'Agricultural technology' includes all kinds of improved techniques and practices which could affect the growth of agricultural outputs (Arora *et al.*, 2009). The most common agricultural technologies include improved varieties of seeds and farm management practices such as soil fertility management; weed and pest management and irrigation and water management. Adoption of these new technologies increases agricultural productivity, which can be seen through the outward movement of the production frontier (Solomon, 2014). Such technologies are believed to be major factors for the success of the green revolution experienced by Asian countries (Colman, 1989).

Fertilizer is one of the most important agricultural technologies used to improve the soil fertility and enhance productivity. The demand of fertilizer increased more than double in the last 10 years. The amount of fertilizer sold in 2002 was 210,000 million tons and in 2012 it was 550,000 million tons representing a 6 percent annual increment (International Fertilizer Development Center (IFDC, 2012). However, the intensity of fertilizer use (i.e.18.5 kg/ha) is below the African countries' average (i.e. 26 kg/ha) (World Bank, 2017). According to CSA (2014) data, in 2014; 8,591,247 hectare of land had used fertilizer. Of the total cultivated land covered by fertilizer, 90 percent where covered by cereal crops and *teff* crop alone constitutes 40 percent.

Improved seed is another agricultural technology which can increase the yield potential. Framers access seeds through formal and informal systems. Both systems operate simultaneously in the country; although the formal seed system is the source of improved seeds it only covers 10 percent of small households seed demand. The remaining 90 percent of seed comes from the informal source. From the total certified improved seed which realized for the market 96 percent are cereal crops (IFDC, 2012).

Row planting is an improved agronomic practice to maximize yield through increasing light exposure and the availability of water and nutrients to plants. Previous literatures revealed that this planting method increased crop yield and decrease the intensity of seed use compared to the broadcasting method (i.e. Broadcasting sowing used 50 kg/ha but row planting used 2.5-3 kg/ha for *teff*). (Vandercasteelen *et al*, 2016).

The current study focused on the productivity of *teff*. *Teff* is the most important economic crop cultivated by 43 percent of small households in Ethiopia covering around 31 percent of the total annual acreage and 21 percent of the total grain production. During the last 19 years the area coverage of *teff* shows 48 percent increment (from 1,385,700 ha in1992/1993 to 2,865,000 ha in 2015/16 (Birrara**,** 2017)). Additionally, more than 50 million Ethiopians use *teff* for different consumption. In recent years, the crop is getting worldwide attention because it is a gluten free crop and it is being served in the form of *teff* breakfast cereals, extruded products, *teff* waffles, *teff* banana bread, composite breads, pasta, malt drinks, cookies, biscuits and cakes. Another potential application of *teff* includes utilization in manufacturing of cosmetics and drugs (ATA, 2016).

The research took some selected districts from the larger regions of the country, *Oromia* and *Amhara*. East and West *Gojjam* zones are taken from *Amhara* region; and East, West and North West *Shewa* zones as samples from *Oromia* region. *Oromia* region is the highest *teff* producer in the country. In this region *teff* is produced on 371,931 ha by 184,923 small households and 324 large scale farmers. The farmers harvested 5,656,16.5 ton. Whereas *Amhara* region is the second largest *teff* producer in the country. The crop is produced by 228,502 smallholders and 426 large scale farmers on 184,648 ha. These farmers harvested about 5,159,33ton, with an average productivity of 2.29 ton/ha (ATA, 2017).

Despite the efforts to increase *teff* productivity, the actual supply of *teff* is well below its demand both in the domestic and foreign market. Although the actual production of *teff* is 2.29 ton/ha, the report of national *teff* research commodity strategy 2016-2030, shows that the productivity of *teff* can be increased by 4.34 ton/ha if farmers could adopt agricultural technologies (such as improved seed, row planting, herbicide and fertilizer). This means the production of *teff* can be increased by 13 million tons in the country. This could increased the income of 6 million people, which could imply to poverty reduction and food security improvement. It could have also created job opportunity along the *teff* value chain. Hence, to enhance the productivity of *teff*, the agricultural technology adoption need to increase. This in turn requires knowing the basic determinants of agricultural technology adoption. In addition to this, the real impact of agriculture technology adoption on productivity needed to be known. Hence, this study attempted to explore the determinants of combinations of three technologies (i.e. Row planting, fertilizer and improved varieties) using the *Amhara* and *Oromia* regional state as a case study.

1.2 Statement of the Problem

According to World Bank (2016), 78 percent of Ethiopians live in rural areas and make their livings from smallholder agriculture; the poverty headcount index for rural Ethiopia is about 26 percent, implying the need for improving agricultural production and productivity to reduce poverty and ensure food security.

Agricultural production could be enhanced either by increasing the area coverage or by increasing the productivity of agriculture (Cleave and Donovan, 1995). However, in the context of Ethiopia land is scarce and hence working on the extensive margin is very difficult. Hence, the feasible way to achieve this goal is through increasing productivity by investing in agricultural technologies or improving the level of technical efficiency (Mohammed, 2014).

Through the diffusion of agricultural technologies, the government of Ethiopia has been striving to enhance agricultural productivity and solve major economic problems such as food price inflation, unemployment and food insecurity and its attempted to get done by an increasing adoption of agricultural technology. For instance, in 1995 a new extension approach known as Participatory Demonstration & Extension Training System (PADETS) was introduced and it is mainly engaged in the delivery of improved seed, fertilizer, and pesticides on credit (at bank interest rate) with a 25 percent down payment. Because of this effort, the number of extension users grew by 10 percent in each year (Admassie and Ayele, 2009).

Despite this fact, the country still has lower rates of technology adoption. For instance the countries fertilizer instance is 18.5 kg/ha which is lower than other African countries and developing countries' fertilizer instance. For instance the East Asian countries fertilizer instance is 327.9 kg/ha, South African fertilizer instance is 58.5 kg/ha, Kenya28.6 kg/ha (World Bank, 2015). Besides, from the country's total land which used for cereal crop production (11.026 million hectare) only (7.38 million of hectare) used improved seed (Ethiopian Grain and Feed Annual Report 2015). As a result the small householders' productivity is lower than the potential productivity due to limited adoption of improved technologies (Gebru, 2014).

This study focuses on *teff* because it is one of the most important staple crops in terms of both production (covering more than 3m hectares) and consumption (more than 50 million people consuming it). Moreover, Due to the presence of higher demand for *teff* in foreign markets. Consequently, the productivity of *teff* has positive relation with the country's economic performance; (i.e. Positive impact on GDP, consumption, employment creation foreign exchange

earnings and food security). As a result enhancing productivity of *teff* helps to solve major economic problems. Although adoption of agricultural technology could increase productivity of *teff*,the adoption decision is handled by individual households. Hence, understanding the constraints to technology adoption and the incentives for such adoption is critical to speed the adoption process.

The determinants of improved technology practice (row planting, improved seed, and fertilizer) adoption and its impact on *teff* productivity have been demonstrated by a number of experimental studies. For instance, the study conducted by Berhan *et* al, (2014) on evaluating the impact of high yield verity and fertilizer on productivity shows that adopters of this technology got higher yield than non-adopters. His study also shows that farmers fertilizer and improved seed adoption decision is positively affected by the sex of the household, land ownership, irrigation use, access to credit, contact with extension agents, and participation on off farm activities. While the chemical fertilizers adoption is negatively affected by distance from home site, and distance to the nearest market. Besides, the adoption of High Yield Varieties (HPV) has a positive and significant relation with land ownership, access to credit, and irrigation use. Both the adoption of High Yielding Variety and fertilizer are negatively affected by age and distance to the nearest market. Consistently, to this study of Hailu *et al*, (2014) shows the positive impact of improved seed on productivity. As their study indicates improved seed verity increases productivity by 10 percent.

Coming to the technology of row planting, there is no agreement regarding the impact it has on yield's of the *teff*. The study of Tesfaye *et al*, (2015) shows that row planting has significant and positive impact on yield of *teff*. Contrary the study of Vandercasteelen, (2016); Berhe, (2015); and Bixen, (2013) mentioned that row planting have insignificant impact on yield of *teff*.

Despite the aforementioned specificities of studies empirical evidence on how households' characteristics, farm characteristics and information access affect farmer's decision to adopt multiple *teff* technologies and their expected payoff for different mix of *teff* technology is minimal. Most of former studies rather shows the impact of single adoption on productivity. Hailu , (2015) for instance assess the impact of improved seed on the productivity of *teff* in *Amhara* region; whereas, both Binx (2013) and Hailu (2014) evaluates the impact of row planting on the productivity of *teff*. But none of them did not showed the impact of multiple technology adoption on the *teff* and their payoff. Whereas, both Binx (2013) and Hailu (2014) evaluates the impact of row planting on the productivity of *teff*. However in reality, farmers adopt more than one

technology in their field and there are interactions between the choices of alternative practices (Menale *et al.*, 2015). Furthermore, most studies the studies have been particularly used Propensity Score Matching (PSM) for instance Hailu (2015); Berhe (2015); Mekonnen (2017); and Tamiru*et al.*, (2013) to examine the impact of a given technology adoption on productivity. But the result of PSM could not show the real adoption impact since the adoption decision have self-selection unobserved endogeinity problem which PSM could not handle (Khandker, 2010).

On the other hand Mohammed (2015) and Teklwold (2013), evaluate the impact of multiple SAP adoption on the income of farm households. However there is minimal research on the impact of multiple agricultural technology (row planting, improved seed and fertilizer) on the productivity of *teff*.

Hence, in an attempt to fill some of the knowledge gaps discussed above and add to the existing limited literature, this particular research conducted an evaluation the determinants of agriculture technology and its' impact of combined and single agriculture technology on productivity by using Multinomial Endogenous Switching Model.

1.3 Research questions

To go through the stated problems, the study bases on the following as research questions:

1. What are the key determinants of technology adoption decision?
2. The effect of technological adoption on productivity?

In an attempt to answer the aforementioned research questions both general and specific objectives of the study are framed in the subsequent way:

1.4 Objectives of the Study

General objective

The general objective of the study is to evaluate the determinants of Agricultural Technology Adoption and its impact on the Productivity of *Teff* in *Amhara* and *Oromia* National Regional State.

The specific objectives are:-

- To identify the key factors that determine simultaneous adoption of improved *teff* Varity, fertilizer and row planting
- To measure the impact of different combination of agricultural technology on *teff* productivity

1.5 Significance of the Study

Comprehensive understanding of farm adoption behavior and its impact on productivity is necessary for sustainable agriculture sector development. This study is expected to have many benefits for various stakeholders'. Some of the studies' result are relevant for policy maker to intervene in to the economy and to enhance productivity. In addition to this the result of the study shows different mix of technologies adoption production payoff. This is important for governmental and non-governmental organization to choice the way of intervention in the economy to enhance productivity. It can also be used as a reference material for researchers who wants further research in this area.

1.6. Scope and Limitation of the Study

The scope of the study is confined to the investigation of the impact of agricultural technology adoption on *teff* productivity in *Amhara* (East and West *Gojjam*) and *Oromia* (East *Shewa*, West *Shewa*, South West *Shewa*) regions. The scope of the study is only *teff*, because it is a main cereal crop in the study areas and it has high demand. In order to achieve the study has used multinomial endogenous switching regression model. The main limitation of this study is lack of data. Even though using panel data is more appropriate to undertake evaluations about the impact of agricultural technology on productivity, the study used cross sectional data since there is no panel which could be used to achieve the objectives of the study. In addition the EDRI collaborated with IFPRY data, which is used in this study didn't include off farm job access, credit availability and mobile access, which are relevant for the adoption decision of agriculture adoption decision.

1.7. Organization of the Paper

This paper is organized into five chapters. The second chapter is the literature review, in which the review of both theoretical and empirical literatures, beside it reviewed overall benefits and production of *teff*. The theoretical literature includes the review of different theories regarding technology adoption and productivity; the empirical review part containing literature of developing countries and Ethiopia regarding determinants of technology adoption and its impact on productivity; whereas the *teff* comprehensive review was done. This is followed by methodology part, which is chapter three of the paper. Chapter four presents the discussion part of the paper. The last chapter, chapter five, presents conclusions and recommendations of the paper.

CHAPTER TWO

LITERATURE REVIEW

This chapter focuses on reviewing both the theoretical and empirical literature on the concepts of technology adoption, productivity and ways of their measurement. The thematic areas incorporated under these reviews are directly framed from the objectives of the study. The theoretical literature focuses on the construction of the concepts of the study whereas the empirical literature focuses on some comparable empirical evidences from developing countries in general and Ethiopia in particular.

2.1. Basic Terms of Technology Adoption

Before the explanations of theoretical literature pertaining to the issue under study, it is worth that some basic terms of technology adoption used throughout the study ought to get defined as follows:

Adaptation- means to modify something in order to make it useful for a new purpose or to adjust oneself to a new situation or circumstance.

Adoption –means to take on, accept or follow a plan, idea or attitude.

Rate of Adoption: means the portion of the members of the society who start to use a new technology or innovation during a specific period of time.

The intensity of adoption: is defined as the level of adoption of a given technology. The number of hectares planted with improved seed (also tested as the percentage of each farm planted to improved seed) or the amount of input applied per hectare will be referred to as the intensity of adoption of the respective technologies (Feder*et al.*, 1985).

2.2. Review of Theoretical Literature

The word productivity define as a ratio between the output and the amount of inputs used. Cognizant to this different scholars have devoted to define this term. According to (Krugman, 1994) definition, productivity is the ratio between output and the amount of input. Productivity growth could be achieved either by adopting new technology (i.e. pesticides, fertilizer, improved seeds, etc.); which is represented by an upward shift of the production frontier or by improving technical efficiency of production by way of improving farmers' education, extension service, etc. The latter will be represented by farmers who operate closer to the existing frontier (Coelli, 1995). This study is mainly concerned with the first option of increasing productivity.

2.2.2 Theoretical literature on Technology adoption

2.2.2.1 Sources of Technological Change

Technology is about the relationship between input and output. Technological change helps to produce the same amount of output with lower input or higher amount of output with smaller inputs (Colman and Young, 1989). Elllis, (1993); stated that like other sectors agriculture sector also implement new technologies which helps to enhance the agriculture productivity by improving the soil fertility or decrease the input utilization (labor, land, and capital). Like other sectors, agriculture sector adopts this new technologies; and these technologies are adopted by the farm households and help them to enhance their productivity (Ellis, 1993).

Ellis, (1993) divided the source of technology adoption in to three major sources of technological changes in the agricultural sector. Learning through experience is the 1st source of technology. As Jarrett (2004) explanation, as farmers' aquaria farming experience and use a given technology for long periods, they become experts on that technology and start to learn from its drawback and upgrade the technology. Similar to this Ellis (1993) advocates that research and development is not the only source of innovation rather farmers may learn through experience and innovate new technology. However, the shortcoming with this source of technological change is that it is hardly applicable in developing countries (Ashenafi, 2006).

The second source of technological change is research and development which are divided into two major categories: applied research and development (R&D) and basic or fundamental research. Applied R&D is designed to solve specific and well-defined practical problems, like improving agricultural crop production. On the other hand, fundamental research focuses on

broader and more fundamental areas of understanding. Fundamental research may be mission-oriented (e.g. fundamental biological research intended to provide a long-term knowledge base to fight cancer or create fuels) or it focus on new knowledge creation without explicit consideration of its use (Bentley, 2015). The R&D may be applied by government, non-government or private sector, but most of the time it is undertaken by the government (public sector) institutions since private sectors may not be willing to engage in the early stage because it is not commercially viable to test new ideas. But, once they see from the public sector experience that the technology works they invest in further development (Colman and Young, 1989).

The last source of technology change is through importing and adapting from developed nations. Colman and Young, (1989) argued that this source of technological change have drawback, since new technology built based on the innovators country context, as a result new technology may not be suited for the importing country (Ibid).

2.2.2.2. Theories of Technological Adoption and Diffusion

According to Ellis, (1993); Colman and Young, (1989) stated that the development of agriculture sector is highly depending on the successful innovation and their speed of adoption. Especially investment in knowledge in the form of science and technology is essential for the countries as well as world agriculture sector development. Many scholars accounted different factor for the lower success of agriculture sector but, lower rate of technology adoption is taken as the major reason for the lower rate of agricultural growth (Ellis, 1993; Colman and Young, 1989).

As mentioned above, adoption is a decision to use or to continue using a given technology. It is quite known that adoption decision is not permanent rather it could change at any time due to a number of reasons (Mishra *et al*., 2015). The definition of adoption according to Fisher *et al*. (2000) the word adoption differs from diffusion. The former stand for an individual decision regarding a given technology while diffusion is a cumulative process by which new technologies are spread among users and measured in consecutive time periods.

The process of adopting new technology has been studied for many years across different scholars. For instance, Rogers' (2003) five-stage model or "the innovation-diffusion model" is the prominent model. According to this model, an individual passes through five stages from hearing about an innovation to adoption, and these stages are described as knowledge, persuasion, decision, implementation and evaluation stages.

Knowledge is the first stage where an individual is aware about new technology and how to use it. In this stage critical question like why, what and how are always raised because individuals want to know more about technology. After an individual became aware about the technology he/she builds favorable or unfavorable attitude towards the new technology that forms the so-called persuasion. The third stage is decision stage where an individual decides to use or not to use a given technology. The last stage is implementation where an individual puts the new technology into use, and at confirmation individuals evaluate the results of the new technology and the individual looks for support for his or her decision. More specifically, Rogers' (2003) five-stage model or "the innovation-diffusion model" is graphically depicted in the subsequent way.

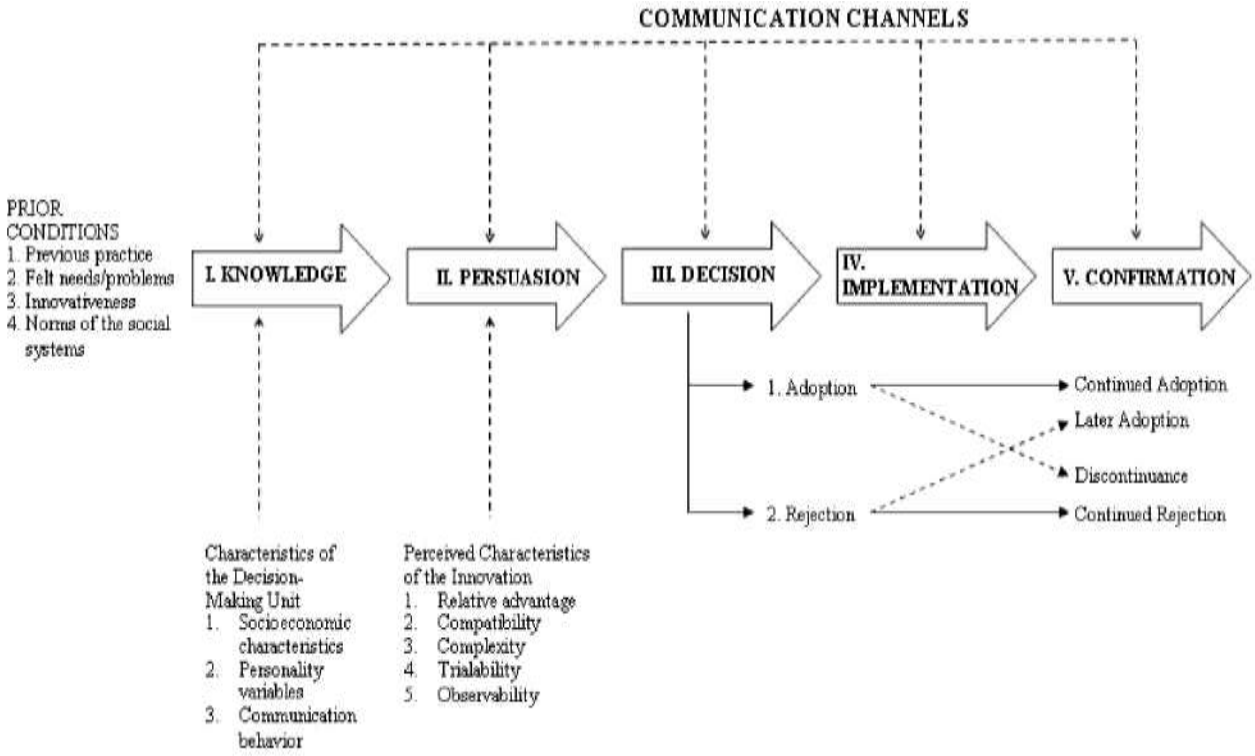


Figure 2.1: The five stages of innovation-decision process (Rogers, **2003**)

Rogers (2003) also classifies adopters into five depending on their tendency to adopt new technology, namely innovators, early adopters, early majority, late majority, and laggards. The distribution of the cumulative process of adoption of the new technology among farmers over time tends to follow the S-shaped curve known as the adoption curve. The S-shaped adoption curve is explained in terms of communication channels and various social characteristics of the potential adopters comprising age, education, attitude towards risk, etc. It shows that the numbers of people that are exposed to the innovation are few in the beginning, since new technologies are coming

from external sources and take time to get accepted by the majority. But, through time people in the social system start accepting the innovation and they bring it in contact with more and more people. This increase the rate of adoption. Eventually, the innovation is accepted by most members of a social system and the rate of spread declines as there is no more member left for accepting the innovation, then spread stops completely.

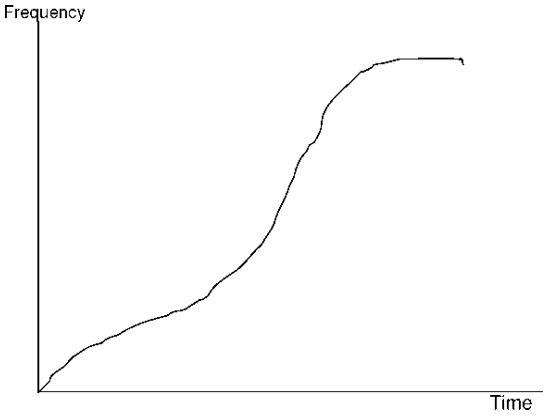


Fig 2.2 source Roger (1983), the S-shaped adoption curve

In line with Roger (2003), DasGupta (1989) also argued that decision to adopt is not normally a single instantaneous act rather it happens through processes. As to him, the adoption is a decision-making process, in which an individual goes through a number of mental stages before making a final decision to adopt an innovation. The decision-making process is the process through which an individual passes from first knowledge of an innovation, to forming an attitude toward an innovation, to a decision to adopt or reject, to implementation of new ideas, and to confirmation of the decision.

2.2.2.3 Adoption Decision and Divisibility

As Feder *et al*., (1985) stated that the adoption decision and the intensity of adoption is made simultaneously in the process of adoption. Farmers always made a decision on whether to adopt individual or aggregate adoption; singular or package of technology; divisible or non-divisible. If the technology is divisible, the level of adoption could be measured at the individual level, which measured the share of the farm area under the new technology or by the per hectare quantity of input used in relation to the resource recommendation. On the other hand, when the technology is indivisible, the aggregate adoption of lumpy technologies can be measured by calculating the percentage of farmers using the new technology within a given area.

2.2.2.4 Speed of Technology Adoption

There is great variation in the speed of technology adoption. Different literatures' had different arguments regarding factors which affect the speed of adoption. On one side, the study by Roger (1983) identifies five characteristics of innovations that have an impact on the speed of adoption. These include: relative advantage, compatibility, complexity, divisibility, and observable. Relative advantage is further sub-divided into economic and non-economic division. The economic category related to the profitability of the technology, whereas the non-economic division shows a function of variables that include saving of time. Another study by Supe (1983) cited in **Hall, (2003)** added two more attributes that affect the rate of adoption: variations in the cost of adoption and group action requirements of the technology. Accordingly, some technologies need group action to implement. For example, technologies such as drainage and watershed management require group actions for adoption compared to technologies that are taken up on an entirely individual basis such as improved seed and fertilizer.

Similar to this Byerlee and Polanco (1986) argued that the adoption pattern of technology is highly determined by profitability, riskiness, divisibility or required initial capital, complexity, and availability. Their study further indicated that the profitability and riskiness of a given technology are a function of agro-climatic and socioeconomic environments, such as rainfall and prices. In other words, rainfall and prices indirectly influence the rate of adoption.

2.2.2.5 Mode of Technology Adoption

There are two modes of adoption in the literature, i.e. adoption of the whole package and sequential or stepwise adoption of the component package. In the adoption of the full package program, farmers are expected to adopt a whole package like Ethiopian Comprehensive Package Program (CPP) and Minimum Package Programs (MPP). This program is highly advocated by technical scientists. Although the package program is highly promoted by the agricultural extension program, mostly such kind of adoption is costly and constrained by resource limitation in Less Developing Countries (Legesse, 1998). Contrary to this Aldana, (2010) advocated that farmers prefer to adopt technology sequentially. i.e., farmers adopt only one type of technology initially and adopt others through time. As he elaborated the main reason farmers' prefer sequential adoption over whole package adoption is to decrease the risk and uncertainty. Further farmers may have lower institutional access of getting the whole package.

In addition to this Ryan and Subrahmanyam, (1975) pointed out that cash constraints is another factor which hinder farmers from adopting the whole package. According to his argument rational farmers with cash constraint will adopt one technology and accumulate cash from their previous adoption of technologies and then they will further adopt another component of the technology package based on the relative advantage and its compatibility under conditions they are operating. This process will continue until the whole package is fully adopted.

2.2.3 Productivity

As mentioned above productivity is defined as a ratio between the output and inputs volume. In other words, it measures how efficiently production inputs, such as labour and capital, are being used in an economy to produce a given level of output (Krugman, 1994). Productivity can be measured in two ways: partial productivity and total productivity. Partial productivity measures the productivity of each input in the production process, like the productivity of fertilizers, HYVS, pesticides and so on, whereas total productivity measures productivity in relation to all inputs (Colman and Young, 1989).

There are different types of productivity measurement, but the choice between them depends on the purpose of productivity measurement and, in many instances, on the availability of data. Broadly, the measurement of productivity classified as single factor productivity measures (relating a measure of output to a single measure of input (i.e. Fertilizer, improved seed)) or multifactor productivity measures (relating a measure of output to a bundle of inputs) (Colman and Young, 1989). Another distinction of particular relevance at the industry or firm level is between productivity measures that relate some measure of gross output to one or several inputs and those of which use a value-added concept to capture movements of output.

Increasing the productivity of agricultural sector is taken as a solution for developing country where there is higher food insecurity and poverty problem. For many decades SSA agriculture production growth depends on the expansion of cultivated land, but today it is difficult to increase the cultivation land. Rather agricultural productivity could be increased by increasing the rate of technology adoption. Increasing the rate of technology adoption in turn requires generation of effective and efficient agricultural technology. Moreover the government of SSA countries needs to draw policy, so farmers apply technology to increase their productivity (Cleave and Donovan, 1995).

As studies relived (Ashnafie, 2006; Mekonnen, 2017; Juma, 2014; Cleave and Donovan, 1995) Adopting of new and improved agricultural technologies have a vital role to increase the productivity of agriculture sector. On other hand Ellis, (1993) argued that the relative success of this technology depends on natural and socioeconomic factors. For instance the study of Otsuka and Kalirajan (2005), shows that the green revolution has significantly increased the productivity of many Asian and Latin American countries. But that is not true in the case of Africa. Because African farmers shown little interest in these technologies. Typically Adoption of HYVS is not applicable in Africa because these varieties generally perform well only under a controlled environment where there is no shortage of water (using irrigation) and where chemical inputs can be widely used. In general, there is little irrigation available and inputs are scarce in Africa. So the problem is not so much of developing HYVS that need a lot of care, but of growing varieties that can adapt to a difficult.

This study doesn't deal with all modern agricultural inputs, rather it only evaluate the impact of improved seed, fertilizer and row planting. Since this technology are highly promoted by the government to enhance the productivity of *teff*.

2.3. Review of the Empirical Literature

Enhancement of agricultural productivity is a major goal for developing nations like Ethiopia. Like other developing nation the government of Ethiopia has also plans to increase productivity of this sector by increasing the adoption of agricultural technology (Chipeta, 2015). But the adoption of agricultural technology decision is different from other sectors' adoption decision since this sector has its own peculiar characteristics like seasonality of production and high dependence on natural phenomena. There are vast literatures regarding factors that determine agricultural technology adoption, and scholars have different views regarding factors that affect technology adoption. For instance, according to Levisohn *et al*. (2013), the decision of adoption and its implementation are conditioned by the dynamic interaction between characteristics of the technology itself and the array of conditions and circumstances. In traditional economic analysis, the adoption decision depends on personal characteristics and endowments, imperfect information, risk, uncertainty, institutional constraints, input availability, and infrastructure (Mwangi and Kariuki, 2015). A more recent strand of literature, on the other hand, incorporated social networks and learning in the categories of factors determining adoption of technology (Uaiene *et al.*, 2009).

These factors are further categorized in to different dimensions for the sake of comprehension For example, Akudugu *et al*. (2012) categorizes agricultural technology adoption into three, namely; economic, social and institutional factors; and McNamara *et al.* (1991) categorized them into farmer characteristics, farm structure, institutional characteristics and managerial structure. Again for further clarity, these factors are classified in to the one that affect the adoption decision in developing and developed nations. This classification is based on the development context of the respective nation. For instance, provided that developing countries agricultural sector is characterized by high dependence on natural phenomenon, highly constrained by shortage of resources and undertaken by less educated farmers (Mwangi and Kariuki, 2015), it is assumed that factors that affect the adoption decision is closely related to this context.

The empirical literature review of this study has three parts: the first part focuses on the factors that determine the adoption decision of farmers in developing countries; the second part focuses on the impact of agriculture technology adoption on productivity; and lastly the third part highlights Ethiopian based studies on technology adoption.

2. 3.1. Adoption and Productivity in the Context of Developing Countries

For the detail analysis on the determinants of agricultural technology adoption, this study classified major factors into four i.e. household head's characteristics, farm characteristics, institutional and agro-climatic factors and the characteristics of the technology.

2. 3.1.1 House Hold Characteristics

The results of many studies on technology adoption decision show that households' characteristics affect the adoption decision. These include variables like sex of the household head, age of the household head, education level of the household head, family size (number), number of active labor (Kinyanjui and Kinuthia, (2017); Ahsanuzzaman. (2014)); Juma, O. M. (2009))

There is no consensus regarding the relation between age and the household's adoption decision. The result of some studies shows that the age has a positive relation with the adoption decision (Juma, 2009); Ahsanuzzaman, (2014); Kinyanjui and Kinuthia, (2017)). Their argument is that in developing countries where most of the farmers are uneducated, the role of experience should not be underestimated. This is to mean as farmers get older they acquired experience and resource that would allow them more possibilities for trying a new technology. Inconsistently, the study of Djido *et al.* (2013); Yu Bingxin *et al.* (2011) shows that age has negative and significant relation with technology adoption. According to them, younger farmers are more likely to adopt new technology because they have had more educated than the older generation.

On the other hand, some studies demonstrated that age has insignificant impact on the adoption decision (Uaiene *et al.* (2011); Mekonnen (2017)). Therefore, the effect of age on adoption depends on specific conditions in the population and area where the new technology is introduced.

The study of Menale *et al* (2015) indicates as education increases the ability to obtain, process and use information, which is relevant for the adoption of a new technology. As a result, each additional year of education increases the probability of adoption. This argument is also supported by Manda (2015); Uaiene *et al.* (2009). Contrary to this, Ahsanuzzaman's (2014), study indicates the absence of significant correlation between years of education and adoption decision.

Family size is another factor which determines the adoption decision. Menale *et al.* (2014) stated the relation between technology adoption decision and family size depends on the type of technology. Family size has a positive impact for labor intensive technologies since family labor is proxy of labor for developing countries. But it has negative impact for capital intensive technologies. Contrast to this, the study of Ahsanuzzaman (2014) show insignificant but positive relation between the two.

Gender of the head of household is another factor which affects the adoption decision. As many studies indicate being women household head decreases the probability of adopting agricultural technology. Coloman and Young (1986) pointed out some factors which accounts for the lower rate of women technology adoption. For instance, men have more economic freedom than women. This emanates from the very fact that women and men have different access of production resources like land, labor and asset. As they noted, in most developing countries ownership of land and asset is recorded by the man's name; even in a condition where the asset comes from the woman's family. This argument is supported by the study of Mekonnen (2017). On the other hand, the study of Juma (2009) shows that the relation between gender and adoption decision is not consistent for all technologies i.e. gender has a positive and significant impact for improved maize adoption but it has insignificant impact for the adoption decision of fertilizer.

2. 3.1.2 Farm Specific Factors

Farm specific factors include variables such as farm size and soil fertility influence farmers' adoption behavior. Farm size has a multidimensional role on technology adoption. Farm size can affect and in turn be affected by the other factors influencing adoption (Lavison, 2013). The impact of farm size on technology adoption depends on the characteristics of the new technology. If the technology has divisible nature, small farmers have high probability to adopt the new technology. But if the technology is in lump sum small farmers have lower probability to adopt new technology. For instance, the study of Menale Kassie (2015); Juma (2009) all show a positive effect of farm size on technology adoption. On the other hand, according to (Ashenafie, 2006), even in conditions where the new technology has a divisible nature, the rate of adoption is higher for larger than smaller farms. This difference happens mainly because of differences in information acquisition. The argument for this is the differences in information acquisition costs, which is unaffordable for small farmers than large farmers which may discourage adopting the technology.

2. 3.1.3 Institutional and Social Factors

Access to information is believed to be an important factor enhancing adoption of agricultural technologies. Farmers always got information either from formal or informal sources. In today's agricultural development, the access to agricultural information is necessary for increasing production. Extension service is one way of delivering information about new technologies for farmers. Having information about new technology motivate farmers to adopt a new technology. Most of empirical studies' results show that frequent contact with extension has a positive and significant relation with the adoption decision of farmers (Menale *et'al*, 2015; Juma, 2009; and Tesfaye *et al*., 2001).

In addition to the formal source, farmers also get information about new technology from informal sources like group membership, which may enable them to learn about a technology via other farmers and from other development agencies (**Muange**, 2014). Information flow between members of farmer groups is usually very rapid and important. Farmer groups give their members a wider opportunity for educating each other. Higher interactions between members of a group increase chances to widen understanding of new technologies and their advantages. Adekambi (2006) observed that the farmers' habit of attending society meetings regularly is one of the factors for having positive and significant effects on farmers' adoption decisions. Likewise, Mohammed (2014) found that the probability of adoption is also higher for farmers organized in groups.

Distance to input and output market could influence the farmers' decision in various ways (Feder *et al*., 1985). Distance could affect the availability of new technologies, information and credit institutions (Menale *et al*., 2015). Input markets may allow farmers to adopt sustainable practices such as seed of improved crop varieties. At the other end, access to output markets may positively enhance farmers to produce more. Besides, distance to input and output market, consider transaction costs which are associated with buying inputs and taking produce to the market. Most of empirical studies shows that market distance has negative and significant impact on technology adoption decision. The study of Juma, (2009); Velarde and Pede (2013) verifies this argument. On the other hand, Menale *et al* (2015) found out that the distance to the input market has a significant and negative effect on the adoption decision. Whereas distance from the output market has insignificant effect technology adoption decision.

Land right: the impact of land right on technology adoption is not clear (Mohammed, 2014) shows that people increase their rate of adoption when they rent land rather than owning land. On the other hand, Gaenn *et al, (2009)* stated that land ownership has no significant impact on technology adoption rather farmers' decision on adoption is affected by other political and social insecurity. Hence, where all things remain constant farmers have equal chance to adopt technology for rented and own land.

2. 3.2. The Relation between Technology Adoption and Productivity

Technology adoption is one way to increase the level of productivity. Different researchers used different methods and indicated adoption of new technology has a positive and significant impact on productivity. For instance, Juma (2009) used difference in difference shows that full technology adopters got higher yield than non-adopter and partial adopters; Menale *et al* (2015) using a multinomial endogenous switching model found out that full package technology adopters got better income than both partial technology adopters and non-adopters; partial adopters got better income than non-adopters. Likewise, using a multinomial endogenous model Khonje *et al* (2014) reported that on average, adopters of a combination of SAPs had between 43 percent and 75 percent more income than non-adopters, with the package of improved maize and residue retention having the greatest income effect.

2. 3.5. Ethiopian Based Studies' on Agricultural Technology Adoption

Different researchers' have evaluated the determinants of technology adoption decision and its impact on productivity, cost of production and households' welfare. Joachim *et al.,* (2017) studied about the impact of distance to the city on the adoption decision by using multivariate variable regression on cross sectional data. His study's result shows the presence of a strong heterogeneity between farmers who are close to and far from the city on productivity, input utilization and profitability. Farmers who are close to the city used more agricultural inputs and they are more productive and profitable than farmers who are far from the city. He further found as transportation directly affect the price, yield per hectare and profitability of *teff*. Moreover, his study result indicates that transportation has an indirect effect on improved seed yield, improved seed usage and profitability of *teff*.

A study undertaken in *Arsi* zone with the objective of evaluating the impact of improved wheat adoption on the productivity of wheat through PSM and used the probit model to calculate the

determinants of technology adoption (Tesfaye *et al.*, 2016). Tesfaye used cross sectional data. According to his study result, education has significant and negative relation with the adoption decision of improved wheat. On the other hand, livestock ownership, sex of the household (when the leader of the house is male), wheat rust disease resistance had a significant and positive relation with the adoption decision of improved wheat varieties. Furthermore, the result of PCM shows that adopters of improved wheat are more productive than non-adopters. Biased, the income of improved wheat adopters is higher than non-adopters by 35 to 50 percent.

The empirical result obtained from *Amhara* region shows that the adopters of agricultural technology have better welfare than non-adopters (Gebreselassie et *al* 2014).Gebreselassie *et al* (2014) used 2013/2014 Ethiopian socioeconomic data. Their study employee Double Hurdle model to examine the determinants of technology and propensity score matching to investigate the impact of technology adoption on welfare of rural households. According to their results, formal education and sex have insignificant relation with the probability of technology adoption. Whereas off-farm employment, land availability, existence of credit facility, agricultural market, physical infrastructure and distance to the nearest market have positive and significant relation with the probability of adoption decision; nearing to all-weather road increase the probability of adopting fertilizer by 0.013 percent and 0.0016 percent, and 40 percent of non-adopters are become non-adopter by the case of lower access to credit. On the other hand, Sebsibiel *et al* (2014) shows that as a farmer used organic fertilizer their probability to adopt non organic fertilizer significantly decrease.

Hailu *et al.* (2015) used stochastic trans log to study the technical efficacy of improved *teff* and he used Cabb-douglas production function to evaluate the impact of high yielding variety on productivity. Hailu used 1200 *teff* producer farmer, as a sample. According to his study result, adoption of high yielding variety increases the productivity of *teff* by 10 percent. In addition, technical efficiency of sampled farmer who adopt a high yield variety was found to be 75percent. This shows that the productivity of *teff* could further increase by 25 percent, if the farmers could improve their technical efficiency. The level of technical efficiency is positively and significantly related with human capital (education, technical training, and cooperative membership), age, family size, and gender.

Berhe (n.d.), evaluated the impact of row planting on the productivity of *teff* in Tigray region by using 300 sampled households. Berhe used PSM to study the impact of row planting on *teff* yield

and he employee Heckman two stage model as robust test. His study results show that the productivity of row planters is higher than broadcast planters by 30 to 50kg/ hectare. The result of Heck man two stage model shows education of the household, size of cultivated land, number of Livestock ownership have a significant relation with technology adoption decision.

Berhanu *et al.* (2014) investigated the basic determinants of chemical fertilizer and HYV by using probit model and evaluated the impact of these technologies on productivity by using OLS in Northern Ethiopia. He used a cross sectional data. The probit regression result shows that gender, land ownership, irrigation use, access to credit, contact with extinction agent, participation on off farm activity have significant and positive relation with the adoption decision of fertilizer and improved seed. While plot distance from the homestead and distance to the nearest market have negative and significant relation with chemical fertilizer adoption decision. The result of OLS shows the adoption of agricultural technology increases the income of technology adopters.

Bayissa (2014) used double hurdle model to examine factors which are influencing adoption decision and intensity of use of improved *teff* technologies in Western *Wollega* on 140 sample farmers. The results showed that experience, participation in crop production training, education level, distance to nearest marketing center and the characteristics of new technologies like yield superiority and maturity of the new crops over local cultivars have a positive and significant effect on the farm households adoption decision and intensity of production of improved *teff*.

Challa and Telihun (2014) studied about the determinants of agricultural technology adoption and its impact on the income of farmer by using probit model and he used PSM method to evaluate the impact of technology adoption on income and output. The PSM result shows that the adopters of agricultural technology got better income and output than non-adopters. The logistic regression result shows that adoption decision has positive and significant relation with education, credit accessibility, attitudes of farmers towards fairness of cost of inputs and having off-farm income & farm size. Whereas family size negatively influenced the decision of household at 5 percent level of significance adoption of modern agricultural technologies.

Mekonnen (2017) used panel data to study the impact of improved agricultural technology on the productivity through PSM and welfare of agrarian households using probit model. According to

her study, education, farm size, labor, credit access, quality of land and livestock asset have positive and significant relation with the adoption decision of chemical fertilizer and HYV. Besides, her study result relives that adopters of agricultural technology got better income than non-adopters.

Mohammed (2014), studied on the impact of multiple SAP adoption on the income of maize producing farmers in Southern Ethiopia by using multinomial endogenous switching model. Mohammed used 340 maize pots form Sidama Zone as a sample. According to his study result socio-economic factors, access to information, credit institution and plot characteristics determine the adoption decision of multiple SAP practices. His study also shows multiple SAP technology adoption have positive and significant impact on the income of maize farmers.

Tesfaye *et al* (2015) studied about the yield and net benefit cost of different *teff* sawing method in *Bedelle* and *Dhidhessa* districts. The study undertake economic evaluation comprising a partial budget with dominance, marginal and sensitivity analysis with CIMMYT (1988).The study compares the economic return from four methods, namely hand broadcasting method, ATA machine broadcasting method, row planting and transplanting method were evaluated. The yield obtained from the row planting was 42 percent higher than hand broadcasting method. The transplanting method improved the yield of *teff* crop by 44 percent than the yield obtained through row planting method. Nevertheless, the net benefit obtained from transplanting (12,670 birr/ha) was found to be 45 percent less than the broadcasting (18476 birr/ha) method. The transplanting method was failed to be an economically feasible option, since it have demanded further refinement with regards to its labor intensiveness.

Yu Bixen and Nin Pritty (2014) studied about the extent and determinants of fertilizer on cereal production by using double hurdle method. According to their study extension service have a vital role in the adoption decision of fertilizer. Furthermore, access to skill and knowledge, risk aversion behavior, land fragmentation and households land ownership are major determines of fertilizer adoption.

Teklewold *et al.*, (2013) employed multinomial endogenous switching model to study the impacts of cropping system diversity, conservation tillage and modern seed adoption on household income, agrochemical use and demand for labor through cross sectional data. The result shows that the

likelihood of adoption of a package of sustainable agriculture practices (SAP) is influenced by observable plot, household and village characteristics. These include rainfall and plot level disturbances; soil characteristics and distance of the plot from home; social capital in the form of access and participation in rural institutions; the number of relatives and traders known by the farmer; market access; wealth, age, spouse education and family size; the farmer's expectations of government support in case of crop failure; and confidence in the skill of public extension agents. The result also shows that the adopter of SAP gained better income and more productive than non-adopters of SAP.

Tamiru*et al.,* (2013) used double hurdle model to investigate the determinants of technology adoption decision and PSM to evaluate the impact of technology adoption on productivity. Their results indicated that being female, daily wage rate, distance to all-weather road, slope of land, color of soil have a positive and significant impact on the adoption decision of agriculture technology. Whereas distance to the city and transportation cost have a negative relation with the adoption decision of agriculture technology. Furthermore, the PSM result showed application of agricultural technology has a positive and significant impact on the productivity of labor.

The study of Vandercasteelen *et al.,* (2013), shows that row planting has, a positive but insignificant impact on yield of *teff*. Rather it has positive and significant impact on the deceasing seed rate. Vanderasteen *et al.,* (2013) employed Randomized control trial by taking 1000 farmers as a sample from 10 words of *Oromia* region.

Debelo (2015) employed PSM to study the impact of Quncho on the income Wayu Tuqa District. Debelo takes 388 households as a sample. According to his study result shows Educational level, owning of farm land, sex of households, productive labor of households in terms' man equivalent, the number of livestock in terms of TLU, number of development agents' contact with the household per cropping year, ability of family food requirements meeting, as well as crops net income of the households were positively associated with adoption of Quncho *teff*. On contrary to this, such covariates as the age of the household head, distance from nearest market centers, number of oxen holdings and investment costs were negatively associated with the adoption of Quncho *teff*. The study also shows that adopters of *Quncho* got 11,790.59 birr higher than non-adopters.

Gebru **(2006)** employed logit model to study the determinants of technology adoption and used Cobb Dagulas model to evaluate the impact of technology adoption on productivity using cross sectional data in *Amhara* and Tigray regions. His findings show that farmers having larger farm size, own large number of oxen, had access to credit, located near to input delivery institutions, being in Woredas which are relatively suitable for agricultural production and had extension contact, household head education level, and being in good agro-ecological woreda have significant and positive effect with the adoption decision. Furthermore, the result of Copp-Dagulas production function shows that in case of Tigray land size has a negative effect on the level of productivity while the number of oxen the household own, other income other than agriculture, access to credit, ownership of radio and being in good agro-ecology woreda have positive impact on productivity. On the other hand, having extension contact and whether the household is classified as adopter doesn't have a significant effect on productivity. In case of *Amhara* region, productivity is negatively affected by land size, having a sick family member in the household and being poor. The number of oxen the household own, usage of modern agricultural inputs, being adopter of the modern inputs and being in suitable agro-ecological Woredas like *Hulet Eju Enese, Enebse Sar Midir* and *Jama* as compared to *Ambasel* positively affect the productivity of the farm households. Having extension contact has a positive, but insignificant effect on production.

From the aforementioned literature, it is apparent that most of the studies proved as adoption of agricultural technology has a positive and significant effect on productivity. The rate of adoption is also determined by household's characteristics, farm characteristics, and social and institutional framework. It is also comprehendible that most of these studies tend to evaluate the impact of single technology adoption on productivity by using PSM and OLS method. While farmers, most likely adopt more than one technology with the presence of interaction with their adoption decision. Besides, OLS method couldn't show the real impact of technology adoption on productivity since technology adoption decision has self –selection an endogeneity problem which make the OLS estimation biased. The result of PSM also could not show the pure impact of technology adoption on productivity, since adoption decision is highly influenced by unobserved factors like skill, knowledge and other unobserved factors, which could not handle by PSM. Beside to this most of studies which evaluates the impact of multiple technology adoption on productivity give more fouces on evaluating the impact of SAP technologies on the outcome variable. However there is minimal literature which evaluates the impact of multiple technology adoption on the

productivity of *teff*. To fill this gap the current study was done, this study evaluate the impact of multiple technology adoption on productivity *teff* by using multinomial endogenous switching model. Unlike PSM and OLS this model control for endoginity problem which arise from both observed and unobserved factors.

2.4 Background to Production, Productivity and Socio- Economic Benefit of *teff* in Ethiopia

Teff (the scientific name of *teff* is *Eragrostis teff* (Zucc.) Trotter) is one of the most important native cereal grain species in Ethiopia both in terms of production and consumption. It has accounted for one-third of the cultivated area and one-fifth of the total production of all cereals grown in Ethiopia (Vandercasteelen *et al.*, **2013**).

Teff grows in areas where the rainfall is 1,000 mm, but the range is from 300 to 2,500 mm. *Teff* resists moderate drought, but most cultivars require at least three good rains during their early growth, flowering, and seed-setting stages, and a total of 200 to 300 mm of water. Some early-maturing cultivars can obtain the 150 mm they need for water retained in soils at the end of the normal growing season. *Teff* has a capacity to survive drought. It is indeed a reliable cereal during unreliable rainfall, particularly when there is unpredictable dry spells. This makes *teff* an important crop for drought-prone and food-insecure areas. Its production is currently expanding to include many drought-prone areas of the country. In terms of temperature, while *teff* has some frost tolerance, it will not survive a prolonged freeze. It also tolerates high temperatures (at its lower altitudinal range) well above 35^{o}C (National *Teff* Research Commodity Strategy (2016-2030), 2016).

Teff produce in almost all regions of the country *Amhara* (i.e. the East *Gojjam*, West *Gojjam*, North *Gonder*, South *Gonder*, North *Wollo*, South *Wollo*, North *Showa*, and *Awi* zones); *Oromia* region (i.e. East *Shewa*, West *Shewa*, Southwest *Shewa*, North *Shewa*, East *Wollega, Horo Guduru,, Jimma, Illuababora*, and *Arsi*) and the Central and South *Tigray* zones take the lion share of the production (*Ibid*).

2.4.1 Production and Productivity of *Teff*

Teff is cultivated widely covers around 31 percent of the total annual acreage and 21 percent of the total grain production. A total production of 4.42 million tons is harvested over a 3.02 million hectare of land. During the last 19 years the area coverage of *teff* showed a 59 percent increment

(from 1.9 million ha in 1994 to 3.02 million ha in 2013) more than any other cereal crops During the same period, production of *teff* increased from 1.86 in 1994 to 4.43 million metric ton, which is about 138 percent, while its productivity rose from 0.98 ton/ha to 1.46 ton/ha, which is almost a 50 percent increment (National *Teff* Research Commodity Strategy (2016-2030), 2016)

In terms of administrative regions, *teff* is produced in seven regions of the country which *Oromia* and, *Amhara* being the major producers (Table 1). There are 19 major *teff*-producing zones in the country. In the *Amhara* Region *teff* grows in 10 zones and the prominent ones being East *Gojjam*, West *Gojjam*, North *Gonder*, South *Gonder*, North *Shewa*, North *Wello*, South *Wello* and *Awi*. Thirteen zones grow *teff* in *Oromia* Region and the major ones being West *Shewa*, East *Wellega, Jima*, East *Shewa*, North *Shewa*, South West *Shewa*, and West *Wellega, Horo Gudru Wellega, Illuababora, Arsi* and West *Arsi* (*Ibid*).

Table 2.2: Area and production of major *teff* growing regions

Region	**Area (ha)**	**The percent share of total area planted**	**Production (ton)**	**Percent share of total production**	**Yield (ton/ha)**
Tigray	165,804	6.01	209,507	6.02	1.264
Amhara	**1,014,268**	**36.77**	**1,279,108**	**36.75**	**1.261**
Oromia	**1,289,405**	**46.74**	**1,671,803**	**48.04**	**1.297**
SNNPR	265,377	9.62	296,759	8.53	1.118
Benishangul	23,648	0.86	23,107	0.66	0.977
Total/average	2,758,502	100	3,480,284	100	1.262

Source: National *Teff* Research Commodity Strategy (2016-2030)

Table 2.3 : Trend of *teff* production between 2003/04-2011-12

Teff	Area (ha)	percent change	Production (t)	percent change	Yield(t/ha)	percent change
2003-04	1,989,068	-	16,773,480	-	0.8	-
2004-05	2,135,553	7.36	2,025,521	20.76	0.9	12.45

2005-06	2,246,017	5.17	2,175,598	7.41	1.0	2.22
2006-07	2,404,674	7.06	2,437,749	12.05	1.0	4.64
2007-08	2,565,155	6.67	2,992,924	22.77	1.2	15.09
2008-09	2,481,333	-3.27	3,028,018	1.17	1.2	4.54
2009-10	2,588,661	4.33	3,179,374	5	1.2	0. 66
2010-11	2,761,190	6.66	3,483,483	9.57	1.3	2.77
2011-12	2,731,112	-1.09	3,497,690	0.41	1.3	1.51
Average	2,396,456	4.85	2,625,002	11.28	1.1	6.05

Source: National *Teff* Research Commodity Strategy (2016-2030), (2016)

2.4.2 Food and Nutritional Use of *Teff*

Teff is one of the consumable cereal crop in Ethiopia having multiple uses. Its most important use is to prepare *injera* (a flatten bread or pancake) which is the most popular food in the country. It is also used to prepare Anebabro, "*tella*" and strong alcoholic traditional liquor *areke* . In recent times, western world is starting to use *teff* to prepare functional and/or gluten free food, products like *teff* breakfast cereals, extruded products, *teff* waffles, *teff* banana bread, composite breads, pasta, malt drinks, cookies, biscuits and cakes. Another potential application of *teff* includes utilization in manufacturing of cosmetics and drugs (National *Teff* Research Commodity Strategy (2016-2030), 2016).

Teff is a nutritious cereal grain with excellent protein, carbohydrate and mineral contents. The nutritional content of the grain is generally comparable to that of the major world cereals like wheat, barley, rice, maize and sorghum (Table 2.3.3). In fact, it is superior in many aspects, particularly in minerals such as iron, calcium, magnesium and zinc. Among the commonly consumed cereals in Ethiopia *teff* grain has got the highest amount of protein, calcium, phosphorous, iron, copper, barium, and thiamin and its energy content is surpassed only by maize. It is considered to have a well-balanced amino acid composition (Hailu , 2014). *Teff* being consumed as a whole grain this makes it's flour, highly rich in fiber and nutrients. As a major component of staple diet in Ethiopia, *teff* plays a vital role in promoting nutrition security in the country. In particular, the consumption of *injera* reference for nutrition data contributes to the prevention of many diseases, including anemia, obesity, osteoporosis, and diabetes type II (Zhu, 2016).

Since *teff* is gluten free it is recommended for people who suffer from gluten protein allergy ailments known as celiac disease. It is also useful for person who suffer diabetics and prevention of obesity since it has a low glycemic index characterized by slow release type starches. In addition to this it used for hookworm and pregnancy related anemia since it is highly rich in iron (*ibid*).

Table2.4: Nutritional content of *teff*

Nutritional Item	White *teff*	Brown *teff*	Mixed *teff*	Finger millets	Barley	Maize	Wheat	Sorghum
Calories (g)	339	336	336	326	334	356	339	338
Moisture (percent)	10.4	11.1	10.7	12.1	11.3	12.4	10.8	12.1
Protein (g)	11.1	10.5	8.3	7.2	9.3	8.3	10.3	7.1
Fat (g)	2.4	2.7	2.9	1.4	1.9	4.6	1.9	2.8
Carbohydrates (g)	73.6	73.1	75.2	77.1	75.4	73.4	71.9	76.8
Fiber (g)	3	3.1	3.6	5.6	3.7	2.2	3	2.3
Ash (g)	2.5	3.1	3.0	3.3	2	1.3	1.5	1.6
Calcium (mg)	156	157	140	386	47	6	49	30
Phosphorous (mg)	366	348	368	220	325	276	276	282
Iron (mg)	18.9	58.9	59	85.1	10.2	4.2	7.5	7.8

Source: National *Teff* Research Commodity Strategy (2016-2030)

2.4.3. The Economic Contribution of *Teff*

Teff has contribution to the economy on production, creation of employment opportunity, consumption and access to foreign currency. Besides its use for consumption by over 50 million Ethiopians it is also exported abroad in the form of "*injra*" and brings foreign currency. The production of *teff* covers around 22 percent of area coverage, which is estimated around 3.02 million hectares and it produced by around 6.42 million households. The total production of *teff* valued as 4 billion USD in 2013/2014 which is the highest value in the country. On the other hand, the wholesale price of *teff* is higher than other crops. As a result, it attracts farmers for further production. In addition to this, *teff* production uses a higher amount of fertilizers and its production process is labor intensive since it used higher amount of labor for land preparation, seeding, harvesting and threshing. This creates job opportunity for daily labors and agribusiness related to agriculture mechanization (working strategy for strengthening Ethiopian's *teff* value chain).

CHAPTER THREE

METHODOLOGY

3.1 Study Area

The study was conducted on 2 zones of the *Amhara* region (East and West *Gojjam*) and three zones of *Oromia* region (East *Shewa*, West *Shewa* and South West *Shewa*).

Oromia region is the most populous and widest region in the country. It is bordered by the states of *Afar*, *Amhara*, and *Binshangul Gumze* in the north; Kenya in the south: state of Somalia in the east, Sudan and State of *Benshangule Gumze* in the west. It has 20 administrative zones. In this region *teff* is cultivated on 371,931ha by 184,923 households. The region's average productivity is 1.717 ton/ha. This study takes 5 *wordas*as (*Adama, Dugda, luma, Ada'a* and *Dano*) from East *Shewa*, 4 wordas as (*Ejere*, *Abuna*, *Aduna gin* and *Gindebere*) from West *Shewa* and 4 words (*Seden*, *Sod*, *Kersa*, and *Becho*) from South West *Shewa* as sample.

West *Shewa* (the so called *Mirab Shewain* Amharic; and *Shawaa Lixaa/Dhihaa* in Oromifaa) is one of the zones of the *Oromia* Region. West *Shewa* is bordered in the south by the Southwest *Shewa* Zone and the Southern Nations, Nationalities and Peoples Region, in the southwest by *Jimma* zone, in the West of East *Welega*, in the northwest by *Horo Gudru Welega*, in the north of *Amhara* Region, in the northeast by North *Shewa*, and on the east by *Oromia* Special Zone Surrounding *Finfinne*. The zone has a total population of 2,058,676, of whom 1,028,501 are men and 1,030,175 women; with an area of 14,788.78 square kilometers.

Southwest *Shewa* (the so called *Debub Mirab Shewa* in Amharic: and *Shawaa Kibba-lixaain* Oromoifaa). South West *Shewa* is also, one of the zones of *Oromia* Region in Ethiopia. Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA), this Zone has a total population of 1,101,129, of whom 556,194 are men and 544,935 women.

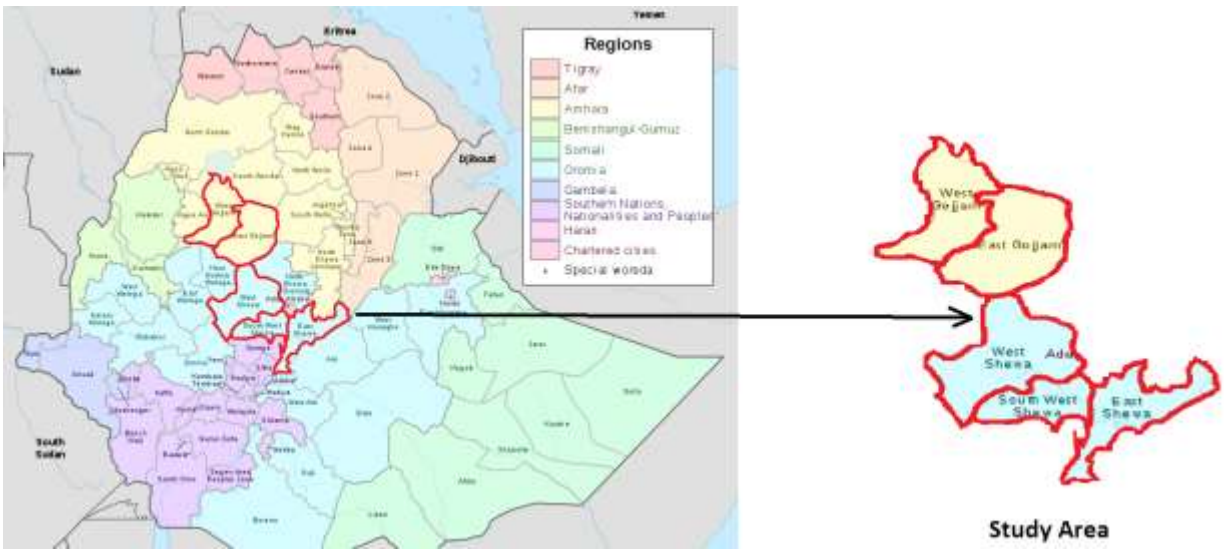
The Eastern *Shewa* Zone is located in *Oromia* region with the population of 135,634. The estimated areal elevation above sea level is 1707 meters. The area coverage of this zone is 8,370.90 square kilometers.

Amhara region is the 2nd most populated region in the country. The region is bordered to the west and northwest by Sudan, to the north by Tigray, to the east by Afar, to west by *Benshangule gumze* and to the south by South West *Orommia*. *Bahrdar* is the region's capital city which is 525 km far from Adiss Ababa. This region has 10 zones and 105 *wordas*. From the total agriculture land

184,648 hectare of land is used for the cultivation of *teff* by 228,502 households. The regions average productivity is 1.699 ton /ha. This study take 4 *wordas* from west *Gojjam* (*sekela, Kurit, Gonji* and *Yilmana*) and 3 *wordas* from east *Gojjam* (*Mechakel, Eenarj ena* and *Shebel*) as sample form this region.

East *Gojjam* (or "*Misraq Gojjam*") is located in *Amhara* region. Its capital city is of *Debre Markos*. *Misraq Gojjam* is bordered in the south by the *Oromia* Region, in the west by *Mirab Gojjam*, in the north by *Debub Gondar*, and in the east by *Debub Wollo*; the bend of the *Abay* River defines the Zone's northern, eastern and southern boundaries. This zone cover around 14,004.47 square kilometers.

Mirab Gojjam (or "West *Gojjam*") is a Zone in the *Amhara* Region of Ethiopia. *Mirab Gojjam* is bordered in the south by the *Abay* River, which separates it from the *Oromia* Region and Benishangul-Gumuz Region, in the west by *Agew Awi*, in the northwest by *Semien Gondar*, on the north by Lake *Tana* and the *Abay* River which separates it from the *Debub Gondar*, and in the east by *Misraq Gojjam*. The population is now estimated to reach ~ 3,800,000; with an area of 13,311.94 square kilometers.



3.2 Data Description

The data for the study come from 1,200 stratified randomly selected households. The survey was conducted by the Economic Development Research Institute (EDRI) and International Food Policy Research Institute (IFPRI). The main purpose of the survey is to understand the *teff* value chains to make recommendations to policymakers to improve the performance of the value chain for farmers, wholesalers, retailers, and consumers. The survey is conducted in 2012 in sixty villages (Kebele) in twenty districts (*Woreda*) in five major *teff* producing zones (regions) of Ethiopia (East *Gojjam*, West *Gojjam*, East *Shewa*, West *Shewa*, and South West *Shewa*).Farmers were randomly selected from both the smallest and largest teff producing *woredas* in these zones. To achieve this, all woredas were ranked in terms of cultivated area within a zone. Two *woredas* then were randomly selected from the top 50% as well as from the bottom 50% producing *woredas*. Within each of the 20 selected *woredas*, all *kebeles* (villages) were ranked in terms of teff production, and two *kebeles* were randomly selected from the top 50% of teff-producing *kebeles* and one from the bottom 50%. Hence, a total of 60 villages was randomly selected. Within each village, a census was created that listed all farmers based on area cultivated. From this list, 20 farmers were randomly selected to be interviewed. Of these 20, ten farmers were selected from the list of large production farmers (cultivating all together 50% of the area) and ten farmers from small production farmers (the other 50% of the area). Hence, a total of 1,200 farmers was surveyed.

The data contained household and plot level information on *teff* production. The data includes 1) *teff* production inputs: land size, seed, labour, fertilizer, herbicides and oxen; 2) type and attributes of technologies: high-yielding seed variety (*quncho* and others) and traditional varieties, crop rotation, type; different colors of seeds, types of fertilizer, mobile phone; 3) plot characteristics: size, slope, soil color, easy of ploughing, walking distance from homestead; 4)farmer characteristics: gender, age, education, household size; 5) Extension: extension visits, agricultural cooperative, community meeting, provision of non-governmental organization, being a model farmer; 6) weather crop shocks: rains level and timing, logging, frost/hailstorm; 7) access to market and services: distance to the nearest dry season road, all-weather road, asphalt/tar road, market place, administrative center, agricultural cooperative, agricultural input dealer.

3.3 Definitions of the Variables Used in the Analysis

Table 3.1 **Descriptions of explanatory variables**

Variable	Description
Agricultural Technology	
F	Fertilizer dummy (1 = yes)
R	Row planting (1 = yes)
I	Improved *teff* variety (1=yes)
Household characteristics	
Gender	Sex of the household head (1 = if male)
Age	Age of the household head, yrs
Education head	Household head education, yrs
Family labor	Family labor (man day power)
Resource constraints	
Farm size	Farm size, hectare
Livestock	Livestock herd (number of live stocks
Asset value	Total value of assets (in birr)
Access to information	
Distance to input	Walking distance to the nearest input
Distance to output market	Walking distance to the nearest main output markets. min.
Distance to asphalt	Walking distance to the nearest asphalt
DA visit frequency	DA visit frequency, in number
Extension visit	1= if they got extension service
Model farmer	1= if the household is mole farmer

Table 3.2: (Continued)

Variable	Description
Plot characteristics	
Plot distance	Plot distance from home,
Tenure	1 = if own plot
Fertile plot*	1 = if good soil quality plot
Moderately fertile	1 = if medium soil quality
Herbicide	Herbicide for plot (birr/ha)
Labor	Labor for farming (day/ha)
Seed	Seed rate (kg/ha)
Fertilizer	Fertilizer rate (kg/ha)

3.4 Analytical and Empirical Model of Technology Adoption

Model choice to study the determinants of adoption decision is based on the number of technologies which are used for study. Binary choice model is the most common way to study single technology adoption behavior. This model often underlies latent variable model and it describe the functional relation between the probability of adoption and various explanatory variables. It assumed that the adoption decision of a given technology is made if the net utility derived from new technology is higher than the existed one. So, the decision to adopt a technology can be modeled as:

$$Y_i^* = x\beta + \varepsilon_i$$

$$were\ is\ Y_i^*\ _{latent\ variable}$$

$$x_i is\ explantory\ variable$$

$$\varepsilon_i is\ error\ term$$

B denotes a vector of coefficients to be estimated.

And the link between the observed binary Y_i and the latent y s made with a simple measurement equation: $Y_i = \begin{Bmatrix} 1\ if\ Y_i^* > 0 \\ 0\ if\ Y_i^* < 0 \end{Bmatrix}$

Where positive value of an observed variable exists when latent variable $Y_i^* > 0$, whereas observed variable $Y_i = 0$ if the latent is negative or zero values. This is basically a latent variable model commonly used to analyze the factors that influence adoption of a single technology (Verbeek, 2004).

Under adoption of multiple agricultural technologies, technology adoption involves the use of a bundle of practices rather than adopting a single practice. This could handle the real world situation, since farmers' most likely wants to adopt more than one technology on their plots to be more profitable. Thus, applying an appropriate model which could simultaneously estimate the effect of explanatory variables on different adoption diction is vital to capture the possible relationship between explanatory variables and the adoptions of different *teff* technology practices. One option of modeling this decision problem is to use a multinomial discrete choice model (Kropko, 2008).

There are many multinomial probabilistic choice models, but the two most widely used models are the multinomial logit (MNL) and multinomial probit (MNP) models. Technically, these models

are very similar, but, they differ only by their error term distribution. The error term distribution of MNL is independent and identically distributed with type I extreme value distribution (log Weibull), whereas MNP assumes that errors are no necessary independently and distributed by a multivariate normal distribution. This difference between MNL and MNP may seem rather minor, but practically it has a big effect. The independent errors of MNL force an assumption called the independence of irrelevant alternatives (IIA) assumption. Essentially, IIA requires that an individual's decision on an alternative relative to other alternative should not change if another alternative is added or dropped from the choice. Nevertheless, this assumption may not always be a very realistic one in many cases (Jonathan, 2008).

Most of the time people assume that MNP model is a better statistical model than MNL since MNP model estimates the error correlations along with the coefficients. Unfortunately, the situation is more complex since calculating choice probability in MNP model is computationally intensive. As explained by Dow & Endersby (2004), choice probabilities in an MNL model are relatively simple, and computers can maximize the resulting likelihood function almost instantly even for a large number of choices. But for MNP, choice probabilities involve multiple integrals, and consequently the MNP may confront a difficult maximum likelihood optimization problem that sometimes fails to converge at a global optimum or produces parameter estimates that are sufficiently inaccurate to make statistical inferences at all. Therefore, Dow & Endersby (2004) argue that MNL is much more stable model than MNP.

Moreover the study of Jonathan (2008) pointed out three reasons that make the MNL model a choice than MNP. First, the estimate with MNP is poor and should not be trusted since the model estimates unconstrained elements of the variance-covariance matrix of the choice errors. Second, MNP will fail to fully converge from time to time, estimating a blown-up variance and highly inflated coefficient point estimates with astronomical standard errors. Third, these problems of MNP in estimating the variance-covariance matrix does not in and of itself mean that MNP will not provide accurate results in certain situations.

Moreover, Scott & Jeremy (2001) argue that if the assumption of IIA choice is hold, in other words if none of the alternatives or technology package can serve as substitutes (no correlation), the results of MNL expected to be very realistic. There are always merit and demerit of choosing statistical model. Given that the current study full fill IIA (seen anixe1) assumption, the current

study employee MNL model to study the determinants of multiple farm technology adoption, since this model gives more accurate estimation result and it is computationally simple to calculate the choice probability

Most of the time the impact of technology adoption on productivity, income and production cost are measured by comparing them across plots adopting different alternative agricultural technologies. However, this method is appropriate for controlling excremental data than observational surveys due to potential self-selection problem. The farmers' decision to adopt or not to adopt is not fully depend on observed factors rather it also depends on unobserved factors like managerial ability, skill, motivation which in turn affects the outcome variables.

Failure to capture these unobserved characteristics may result in inconsistent and biased estimates. In order to control this problem, this study uses a multinomial Endogenous Switching Regression framework following Falco and Veronesi (2013). Thus, in the first stage farmers' decision on adoption of *teff* technology combination is modeled using a multinomial logit selection model, recognizing the interrelationship among the choices, Where as in the second stage the impact of each combination of *teff* practice on outcome variable, productivity of *teff*, is evaluated using multinomial endogenous switching regression model.

3.5 Conceptual Framework

Agricultural technologies are usually introduced in packages which include several components. These components could be complimentary or sequential (adopted independently) (Feder et al., 1985). Obviously farmers adopt a combination of technologies and there is often an interaction between the adoption decisions (Menale, 2015). Adoption of a combination of adaptation practices may not be random, but farmers endogenously self-select themselves into adoption/non-adoption decisions, so decisions are likely to be influenced by unobservable characteristics that may be correlated with the outcomes of interest. This brings a sample selection bias problem which leads to inconsistent estimators. Hence to evaluate the pure impact of agriculture technologies (i.e. row planting, fertilizer and improved seed) adoption on productivity; this study used multinomial endogenous switching model. This model assumed that farmers are utility maximizers and they always compare their utility with the adoption of FIR (fertilizer, improved seed and row planting) with the other technologies. If the farmer got higher utility by adopting FIR, then they will not adopt alternative technologies or vice versa. The model simultaneously estimates the choice and

the outcome equations to show the pure impact of technology adoption. In the 1st step the researcher modeled the farmer's choice with the combination of FIR (fertilizer, improved seed and row planting) using multinomial logit selection model and in the second stage the impact of adoption on productivity using OLS by adding inverse Mills ratio as a correction term which is calculated from the multinomial logit models in order to reduce the bias from not accounting for selection into the adoption decisions.

> *"This approach allow as to get consistent and efficient estimate of the selection process and a reasonable correction for the outcome equations, even when the assumption of the independence of irrelevant alternatives (IIA) is not achieved .This framework has the advantage of evaluating both individual and combined practices, while capturing the interactions between the choices of alternative practices* (Wu and Babcock, 1998; Mansur et al., 2008, cited in Menale, 2015)."

Table 3.3: Alternative Agricultural Technology Adoption

	Choice	Row planting		Fertilizer		Improved seed	
		$R0_o$	R_1	F_o	F_1	I_o	I_1
1	$R_oF_oI_o$	x		x		x	
2	$R_oF_oI_1$	x		x			x
3	$R_0F_1I_0$	x			x		x
4	$R_1F_0I_0$		x	x		x	
5	$R_1F_1I_o$	x		x			
6	$R_1F_0I_1$		x	x			x
7	$R_0F_1I_1$	x			x		x
8	$R_1F_1I_1$		x		x		x

3.6. Multinomial Endogenous Switching Model

3.6.1 Multinomial Logit Selection Model

This study uses MNL to study the determinants of farmers' decisions on adoption of multiple agriculture technologies. According to (Jonathan,2008) in conditions where the IIA assumption is full field MNL model is chosen over MNP, since MNL is much more stable model than MNP. Beside MNL model is relatively simple, and computers can maximize the resulting likelihood function almost instantly, even for a large number of choices.

Assuming that the aim of a farmer is to maximize his productivity, U_{ij}^{*} , the requirement for a farmer "i" to choose package "j" (1,…,n), over "m" the amount of utility obtained from alternative packages (U_{im},). If the farmers obtain higher utility from technology "j" than "m" then he/she will adopt, "j", ($U_{ij} > U_{im}\ if\ m \neq j.$); or equivalently $\Delta U_{im} = U_{ij} - U_{im} > 0\ m \neq j$. The expected profit U_{ij}^{*} , that the farmer derives from the adoption of a package "j" is a latent variable determined by observed household, plot and location characteristics (X_i) and unobserved characteristics (ε_{ij}):

$$U_{ij}^{*} = ¥ + a_j Z_i + \varepsilon_i \dots\dots\dots\dots\dots\dots\dots (1)$$

Where

U_{ij}^{*}: Expected profit obtained from technology j

Z_i: observed characteristics such as (Gender, Sex of the household head, Age of the household head, Education level of the house hold head, Family labor (number), Asset value (in birr),Walking distance to the nearest input markets in min, Walking distance to the nearest main output markets in minute , Group membership, soil type, co-operative membership, attaining community meeting).

ε_i: Captures all the variables that are relevant to the farm household's decision maker are unknown to the researcher such as skills or motivation.

The utility that gained from adopting new technology is not observed, but the technology adoption decision is observed. A farmer will choose FIRs (fertilizer, improved seed and row planting) combination "j" with respect to adopting any other "m" technologies if:

$$U_{ij} = \begin{cases} 1 & U_{i1}^{*} > max_{m \neq j} U_{im}^{*} \text{or } \dot{\eta}_{i1} < 0 \\ & \vdots \\ j & U_{ij}^{*} > max_{m \neq j} U_{im}^{*} \; or \; \dot{\eta}_{ij} < 0 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where $\dot{\eta}_{ij}$is the expected productivity difference between alternative package "*j"* and any other alternative package "m". Therefore $\dot{\eta}_{ij} = \max(U^{*}_{mi}-U^{*}_{ji})<0$ equation (3) indicates that i^{th} farmer adopt "*j"* package if it make him/her more productive than any other alternative "*m"* package were *"m"≠ "j"*.

Assuming that $\varepsilon_i$is independently and identically Gumbel distributed, so the probability that, the farmer "ith" with characteristics "X_i" will choose package "j" can be specified by a multinomial logit model (Falco and Veronesi (2013)).

$$Pij = pr(\dot{\eta}ij < 0/x) = \frac{ex(Z_{ji}\alpha_j)}{\sum_{m=1}^{n} \exp(Z_{ji}\alpha_m)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The latent variable parameter in equation 3 could be estimated on the context of the maximum likelihood function.

3.6.2 Outcome Equations of Endogenous Switching Regression

In the **second stage** the multinimial endogenous switching regression model evaluates the relationship between the outcome variable (Y_j) and explanatory variables (X_i) for each of the alternative packages. "Y_j" is observed when alternative "j" is adopted. Although there are 8 combination alternatives technology choices, this study used only five of them; because the remaining three alternative choices each takes less than 1 percent of the sample population. Hence analyzing these choices is not detectible. In the model specification farmers are considered as non-adopters if they didn't adopt any technology ($F_0I_0R_0$) whereas they are considered as adopter if they adopt at list one *teff* technology (j = 2, …, 8). The outcome equation for each possible regime "j" is given as:

$$regime\ 1\ Y_{i1} = X_i\beta_1 + U_{i1}\ if\ A = 1$$

$$regimej\ Y_{ij} = X_i\beta_j + U_{ij}\ if\ A = j \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where

$$Y_{ij}\ are\ the\ outcome\ variable\ of\ the\ i^{th}\ farmer\ in\ regime\ "j",$$

$$U's\ are\ distrbuted\ with\ E(U_{ij}/X,Z) = 0\ and\ var(U_{ij}/X,Z) = \sigma_j)$$

X_i *'s* are exogenous variables that affect the outcome variable,

Y_{ij} is observed if, and only if, package j is used, which occurs when

$$U_{ij}^{*} > \max U_{im}^{*}\ where\ m \neq j,$$

If the ε's and u's are not independently and identically distributed, OLS estimates in Eq. (5) will be biased. A consistent estimation of β_j requires inclusion of the selection correction terms of the alternative choices in Eq. (5). The Dubin and Daniel McFadden, (1984) model assumes the following linearity assumption to account this bias. The model assumes that the expected value of $U_j\ and\ \varepsilon_j$are linearly related, such that

$E\left(U_{ij}/\varepsilon_{i1} \dots \dots \dots \dots \dots \varepsilon_{ij}\right) = \sigma_j \sum_{m\neq j}^{j} \rho_j\ (\varepsilon_{im}\text{-}E(\varepsilon_{im})$

Where

$\sum_{m\neq j}^{j} \rho = 0$; (by construction, the correlation between u's and ε's sums to zero). Using this assumption, the equation of the multinomial ESR in Eq. (5) is specified as:

$$Y_{i1} = X_i\alpha j + \sigma\widehat{\lambda_{\text{i1}}} + \omega_{\text{i1}} \text{ if Ai} = 1 \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (5)$$

.

$$Y_{ij} = X_i B_j + \sigma\widehat{\lambda_{\text{ij}}} + \omega_{\text{ij}} \text{ if Ai} = \text{j} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (6)$$

Where: $\lambda = \sum_{j}^{m} \rho_{j\,j}(\frac{\hat{P}_{im}\, ln(\hat{P}_{im}}{1-\hat{P}_{im}} + \ln(\hat{P}_{ij}))$ is the invers mile ratio.

P_{ij} represents the probability that i[th] farm household chooses technology "*j*";ρ_j represents the correlation between $\varepsilon_{ij}$and U_{ij}; and $\omega_{ij}$is a residual term which is orthogonal to all ε_{ij}& $E(\omega_{ij})=0$. Practically, the model in Eq. (5) has heteroskedasticity problem that arise from the computation of inverse mills ratio$\hat{\lambda}$. In addition, standard errors are bootstrapped to account for the heteroskedasticity arising from the two-stage estimation procedure.

For the model to be identified, it is important to use exclusion restriction not only those selected by non-linear model (in equation1), but also other variables that directly affect the selection variable but not the outcome variable. The reason for this exclusion restriction is that the inverse Mill's ratio is a non-linear function of the explanatory variables in the multinomial logit equation; thus, the second stage equation (i.e. productivity equation) is identified because of this non-linearity.

However, the non-linearity of the inverse Mill's ratio is not normally tested or justified. Therefore, in order to make the source of identification clear, it is advisable to have an explanatory variable in the multinomial logit equation, which is not included in the second stage outcome equation (Greene, 2003). The explanatory variables that are only included in the multinomial logit specification to meet this exclusion restriction In case of this study we use agriculture extension visit, DAs' visit, asset value, community meeting, co-operative membership, walking distance from home to plot, and parcel ownership used as selection instruments. This study establishes admissibility of these instruments by performing simple falsification test. If the variables are valid selection instruments, they will affect the decision of choosing an adoption strategy; but it will not affect the net productivity among farm households that did not adapt (Falco and Veronesi, 2013). Table 4A in the appendix show valid selection instruments. They are jointly statistically significant drivers of the decision to adapt strategy "*j"* but not of the productivity by the farm households that did not adapt at the 10 percent statistical significance level.

3.6.3 Building up a counterfactual analysis

Multinomial endogenous switching model is important framework to evaluate the impact of multiple treatments on the outcome variable when there is self-selection problem. This method builds counterfactual as follow:

In particular, one can follow Falco and Veronesi, (2013), and derive the expected net output of farm households who adopted, that in our study means j=2,..7) 'non-adopting' "j=1"

Productivity of Adopters with adoption of "j" combination (actual)

$E(Y_j/A=j,X_{ji}, \lambda_{ji})=B_jX_{ji}+ \sigma_{je}\lambda_{ji}$…….(6a)

Productivity of Adopters without adoption (counterfactual) .

$E(Y_{1i}/A=j,X_{ji}, \lambda_{ji})=B_1X_{ji}+ \sigma_{1e}\lambda_{ji}$…….(6b)

Non adopters productivity without technology adoption (actual)

$E(Y_{1i}/A=1,X_{1i},\lambda_{1i})=B_1X_{1i}+\sigma_{1e}\lambda_{1i}$…….(7a)

Non-adopters productivity if they adopt "j" combination of technology (counterfactual)

$E(Y_{ji}/A_i=1, X_{1i},\lambda_{1i})=B_{ji}X_{1i}+ \sigma_{je}\lambda_{1i}$…….(7b)

This allows us to calculate the treatment effects (ATT), for example, as the difference between equations (6a) and (6b).

$ATT= E(Y_{ji}/A=j,X_{ji}, \lambda_{ji})- E(Y_{1i}/A=j,X_{ji}, \lambda_{ji})=X_{ji}(B_{ji}-B_{1i})+\lambda_{ji}(\sigma_{je} - \sigma_{1e})$ …….8

The first term on right hand side of Eq. (8) represent the expected change of outcome in adopters of agricultural technology ($j = 2..8$);if adopters had the same characteristics as non-adopters. The second term (λj) is the selection term that captures all potential difference between adopters and non-adopters which arise due to unobserved variable.

Similarly, the average treatment effect on untreated (TU) is calculated as the deference between (7a) and (7b):

$$ATU= E(Y_{ji}/A=1,X_{1i},\lambda_{1i})- (Y_{1i}/A=1,X_{1i},\lambda_{1i})= X_{1i}(B_j-B_1)+\lambda_{1i}(\sigma_{je} - \sigma_{1e}) \quad \text{.....9}$$

The right hand side of the model shows expected change of non-adopter output if they decide to adopt agricultural technology given that adopters had the same characteristics as non-adopters.

On the other hand base heterogeneity of adopter is calculated as the difference between 7(b) and 6(a)

$$E(Y_{1i}/A_i=j, X_{ji},\lambda_{ji}) - E(Y_{1i}/A=1,X_{1i}, \lambda_{1i})=B_{1i} (X_{ji} -X_{1i})+ \sigma_{je} (\lambda_{ji} - \lambda_{1i}) \quad \text{…….(10)}$$

The right hand side of equation 10 shows the productivity difference of technology adopter and non-adopters without technology adoption. Base heterogeneity of non-adopters are calculated as the difference between 7(a) and 6(b)

$$E(Y_{ji}/A_i=1, X_{1i},\lambda_{1i}) - E(Y_{ji}/A=j,X_{ji}, \lambda_{ji})=B_{ji} (X_{ji} -X_{1i})+ \sigma_{je} (\lambda_{ji} - \lambda_{1i}) \quad \text{…….(10)}$$

The right hand side of equation 10 shows the productivity difference of adopters and non-adopters when both groups adopt similar technology.

Moreover the conditional expected outcome is used to calculate transitional heterogeneity(TT). Transitional heterogeneity is the difference between treatment effect on treated (TT) and treatment effect on untreated (TU). It provides information, whether the effect of adopting agricultural technology is larger or smaller for households that actually had adopted the technologies or for non-adopters in the counterfactual case.

Table 3.4. Treatment and Heterogeneity effect

Sub sample	Decision strategy				
	To adopt				Not To adopt
	$F_1I_0R_0$	$F_1I_0R_1$	$F_1I_1R_0$	$F_1I_1R_1$	
Non adopter house hold	$E(Y_{2i}/A = 1 = X_1\alpha_2 + \sigma_2\lambda_{1i})$ (a)	$E(Y_{3i}/A = 1 = X_1\alpha_3 + \sigma_3\lambda_{1i})$ (b)	$E(Y_{4i}/A = 1 = X_1\alpha_4 + \sigma_4\lambda_{1i})$ (c)	$E(Y_{5i}/A = 1 = X_1\alpha_5 + \sigma_5\lambda_{1i})$ (d)	$E(Y_{1i}/A = 1 = X_1\alpha_1 + \sigma_1\lambda_{1i})$ (e)
TT1	(j)-(f)	(o)-(l)	(u)-(s)	(z)-(y)	
TU1	(a)-(e)	(b)-(e)	(c)-(e)	(d)-(e)	
TH1	((j)-(f))- ((a)-(e))	((o)-(l))-((b)-(e))	((u)-(s))-((c)-(e))	((y)-(z))- ((d)-(e))	
Farm house holds who only adopt fertilizer	$E(Y_{2i}/A = 2 = X_2\alpha_2 + \sigma_2\lambda_2)$ (f)	$E(Y_{3i}/A = 2 = X_2\alpha_3 + \sigma_3\lambda_2)$ (g)	$E(Y_{4i}/A = 2 = X_2\alpha_4 + \sigma_4\lambda_2)$ (h)	$E(Y_{5i}/A = 2 = X_2\alpha_5 + \sigma_5\lambda_2)$ (I)	$E(Y_{1i}/A = 2 = X_2\alpha_5 + \sigma_5\lambda_2)$ (J)
TT2		((k)-(n))	(q)-(s)	(v)-(z)	(a)-(e)
TU2		(g)-(f)	(h)-(f)	(i)-(f)	(j)-(f)
TH2		((k)-(l))-((g)-(f))	((q)-(s))-((h)-(f))	((u)-(z))- ((i)-(f))	((a)-(e))-((j)-(f))
Farm house holds who adopt fertilizer and row planting	$E(Y_{2i}/A = 3 = X_3\alpha_2 + \sigma_2\lambda_3)$ (K)	$E(Y_{3i}/A = 3 = X_3\alpha_3 + \sigma_3\lambda_3)$ (L)	$E(Y_{4i}/A = 3 = X_3\alpha_4 + \sigma_4\lambda_3)$ (M)	$E(Y_{5i}/A = 3 = X_3\alpha_5 + \sigma_5\lambda_3)$ (N)	$E(Y_{1i}/A = 3 = X_3\alpha_1 + \sigma_1\lambda_3)$ (O)

|TT3	(g)-(f)		(r)-(s)	(w)-(y)	(c)-(e)
TU3	(k)-(l)		(m)-(l)	(n)-(l)	(o)-(l)
TH3	((g)-(f))-((k)-(l))		((r)-(s))-((m)-(l))	((y)-(z))-((n)-(l))	((e)-(c))-((o)-(l))
Farm house holds who adopt fertilizer and improved seed	$E(Y_{2i}/A = 4 = X_4\alpha_2 + \sigma_2\lambda_4)$ (Q)	$E(Y_{3i}/A = 4 = X_4\alpha_3 + \sigma_3\lambda_4)$ (R)	$E(Y_{4i}/A = 4 = X_4\alpha_4 + \sigma_4\lambda_4$ (S)	$E(Y_{5i}/A = 4 = X_4\alpha_5 + \sigma_5\lambda_4$ (T)	$E(Y_{1i}/A = 4 = X_4\alpha_1 + \sigma_1\lambda_4$ (U)
|TT4	(h)-(f)	(m)-(l)		(x)-(y)	(c)-(e)
TU4	(q)-(s)	(r)-(s)		(t)-(s)	(u)-(s)
TH4	(((h)-(f))-((q)-(s))	((m)-(l) –((r)-(s))		((x)-(y))-((t)-(s))	((e)-(c))-((u)-(s)))
Full technology adopters	$E(Y_{2i}/A = 5 = X_5\alpha_2 + \sigma_2\lambda_5$ (V)	$E(Y_{3i}/A = 5 = X_5\alpha_3 + \sigma_3\lambda_5$ (W)	$E(Y_{4i}/A = 5 = X_5\alpha_4 + \sigma_4\lambda_5$ (X)	$E(Y_{5i}/A = 5 = X_5\alpha_5 + \sigma_5\lambda_5$ (Y)	$E(Y_{1i}/A = 5 = X_5\alpha_1 + \sigma_1\lambda_5$ (Z)
TT5	(i)-(f)	(n)-(m)	(t)-(s)		(e)-(d)
TU5	(v)-(y)	(w)-(y)	(x)-(y)		(z)-(y)
TH5	(((i)-(g))-((z)-(y))	((n)-(m))-((w)-(y))	((j)-(s))-((x)-(y))		((e)-(d))-((z)-(y))
	BH(A1)	BH(A2)	BH(A3)	BH(A4)	BH(A5)
$F_0I_0R_0$		f-a	i-b	c-s	d-y
$F_1I_0R_0$	$e - j$		i-g	h-s	i-y
$F_1I_0R_1$	e- o	f-k		m-s	n-y
$F_1I_1R_0$	e-u	f-q	i-l		t-y

$F_1I_1R_1$	$e-z$	f-u	i-w	x-s	
	BH(B1)	BH(B2)	BH(B3)	BH(B4)	BH(B5)
$F_0I_0R_0$		f-e	o- e	z- e	z- e
$F_1I_0R_0$	$a-f$		k-f	u-f	v-f
$F_1I_0R_1$	$b-l$	g-l		r-l	w-l
$F_1I_1R_0$	c-s	h-s	m-s		x-s
$F_1I_1R_1$	d-y	i-y	n-y	t-y	

BH(A1) base heterogeneity effect for non-adopters, BH(B1) base hetroginity effect for adopters
BH(A2) base heterogeneity effect when other alternative technology adopters become fertilizer adopters, BH(B2) base hetroginity effect when $F_1I_0R_0$ adopters become other alternative technology adopters
BH(A3) base heterogeneity when other technology adopters adopt become $F_1I_0R_1$, BH(B3) base heterogeneity effect when $F_1I_0R_1$ adopters adopt become other technology adopters
BH(A4) base heterogeneity when other technology adopters adopt $F_1I_1R_0$, BH(B4) base heterogeneity effect when $F_1I_1R_0$ adopters adopt other technology.
BH(A5) base heterogeneity when other technology adopters adopt $F_1I_1R_1$, BH(B5) base heterogeneity effect when $F_1I_1R_1$ adopters adopt other technology.
TH(1) is transitional heterogeneity effect between non-adopters and adopters .
TH(2) is transitional heterogeneity effect between fertilizer adopters and other alternative technology adopters.
TH(3) is transitional heterogeneity effect between fertilizer adopters and improved seed adopter(F_1 I_1 R_0) and other alternative technology adopters
TH(4) is transitional heterogeneity effect between fertilizer adopters and row planting adopter(F_1 I_1 R_0) and other alternative technology adopters .
TH(5) is transitional heterogeneity effect between full technology adopter(F_1 I_1 R_0) and other alternative technology adopters.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Descriptive Statistics

The current study uses EDRI and FPRI's data collected from 1200 *Teff* producing farm households from 2800 plots in 2012. The data were collected from 2 zones of the *Amhara* and 3 zones of *Oromia* regions. As shown in Table 1 below, 595 sample households are selected from eastern *Gojjam*, 457 from West *Gojjam*, 614 from East *Shewa*, 501 from West *Shewa* and the remaining 663 from South West *Shewa*.

Table 4.1: Sample plot distribution by zone

Zone	Freq.	Percent
East *Gojjam*	595	22.02
West *Gojjam*	457	16.14
East *Shewa*	614	21.69
West *Shewa*	501	17.70
South West *Shewa*	663	23.42
Total	2,830	100

4.1.1 Input Utilization of *Amhara* and *Ormoia* Region

As table 2 shows, the total average productivity of *teff* in *Amhara* and *Oromia* region is 1080.72 with the SE of 12.01 in 2012. But the average productivity of *teff* varies among zones, (i.e. Eastern *Gojjam* =1475.55, West *Gojjam*=1065.2, Eastern *Shewa* =1191.45, West *Shewa* =874.58, and South West *Shewa* = 790.35). Fertilizers (DAP and UREA), improved seed, herbicide, land and labor were considered as inputs for *teff* production by farm households.

The average area of land which was used for *teff* is less than one hectare in all zones and the SE shows lower variation in land usage. As table 2 shows, in all zones except East *Gojjam*, the intensity of DAP is higher than that of UREA. West *Gojjam* is the highest utilizer of DAP (128.65kg/ha with SE 9.74) followed by South West *Shewa* (90.91 kg/ha). But the average intensity of UREA and DAP is lower than the amount recommended by extension agents.

The average use of improved seed by both regions is 12.47 kg/ha with the standard error of 0.41; but there is variation in seed utilization among zones. For instance, South West *Shewa* is the highest seed user (14.61kg/ha) with SE of 0.76 followed by West *Gojjam* (12.42 kg/ha) with SE 1.02; whereas, the west *Shewa* zone was the least seed utilizer (4.04kg/ha) with SE 0.56.

The average expenditure of regions to purchase herbicide is 38.93 birr/ha with SE of 0.98. West *Shewa* is the highest utilizer of herbicide (76.76) with SE of 2.79 followed by West *Gojjam* (45.14) with SE of 3.80. Labor is the last but not least input for *Teff* production, which is measured in man-days hour. The region's average utilization of labor is 27.61 with SE of 0.70941.West *Shewa* is the highest utilizer labor (34.47) with SE 2.540299; Whereas, South West *Shewa* with (to 22.36 with SE 0.62.

Table 4.2: production function by Zone

Variables	Eastern *Gojjam*	West *Gojjam*	Eastern *Shewa*	West *Shewa*	South West *Shewa*	Total
	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)
Urea/ha (kg)	127.88 (16.42)	62.84 (3.10)	48.84 (2.1)	50.37 (3.02)	64.41 (1.87)	71.64 (3.62)
Dap/ha (kg)	79.59 (2.99)	128.65 (9.74)	92.56 (2.62)	67.84 (3.34)	90.97 (7.39)	90.91 (2.58)
Herbicide birr/ha	6.17 (0.98)	45.14 (3.79)	37.83 (1.21)	76.76 (2.79)	36.46 (1.01)	38.93 (0.98)
Area/ha	0.37 (0.01)	0.33 (0.01)	0.83 (40.03)	0.66 (0.02)	0.79 (0.03)	0.61 (0.01)
Labor	22.44 (0.75)	22.35 (0.62)	32.19 (2.11)	34.47 (2.54)	26.41 (0.95)	27.60 (0.71)
Recommended DAP/ha	117.71 (4.8)	135.67 (6.01)	121 (3.59)	106.49 (4.47)	117.87 (3.07)	120.57 (1.99)
Recommended urea/ha	128.86 (7.54)	104.72 (5.49)	69.23 (2.41)	84.20 (4.87)	86.14 (3.35)	93.48 (2.26)
Improved seed usage	7.65 (6 .62)	12.42 (1.02)	21.77 (1.24)	4.04 (0.56)	14.62 (0.76)	12.48 (0.413361)

Productivity(kg/ha)	1475.47 (31.93)	1065.22 (28.75)	1191.46 (25.07)	874.58 (19.05)	790.36 (16.38)	1080.72 (12.01)

4.1.2 Alternative Adoption and Their Frequency

As table 4.3 indicates, from the total 2800 sample plots, only 5.1 percent plots adopt full technology. While 47.71 percent of the plots adopts single technology, where as 46.29 percent of plots adopt fertilizer, 0.57 percent plots adopt improved seed and 0.85 percent plots practice row planting), 46 percent of the plots adopted mixed technology (35.97 percent of them fertilizer and improved seed adopters ($F_1I_1R_0$), 4.84 percent where row planting combine fertilizer adopters, ($F_1I_0R_1$) 0.57 percent plots adopted row planting combined with improved seed). This study did not include plots which adopted the row planting and improved seed ($F_0I_1R_1$), single row planting adopters ($F_0I_0R_1$) and single improved seed adopters ($F_0I_1R_0$) for analysis since their proportion is less than one percent.

Table 4.3: Alternative agriculture technology adoption for *teff* and their frequency

Adopt	Freq.	Percent
$F_0I_0R_0$	178	6.29
$F_0I_0R_1$	24	0.85
$F_1I_1R_1$	1,310	46.29
$F_0I_1R_0$	16	0.57
$F_1I_1R_0$	137	4.84
$F_0I_1R_1$	3	0.11
$F_1I_1R_0$	1,018	35.97
$F_1I_1R_1$	144	5.09
Total	2,830	100

Note: agriculture technology represents the eight possible combination of improved *teff* variety (I), row planting (R), & fertilizer (F)
Subscript 1=adoption, whereas 0=no adoption. Total Sampled plot=2830

Source: Own calculation

4.1.3 Descriptive Statistics' for Explanatory Variables

The descriptive statistics of explanatory variables for the five alternative packages considered by this study are presented in Table 4.4. The explanatory variables' mean value of non-adopters ($F_0I_0R_0$) is used as a reference category to compare with mean values of adopters ($F_1I_0R_0$, $F_1I_1R_0$, $F_1I_0R_1$ and $F_1I_1R_1$). The result shows that the mean values of explanatory variables are significantly different across the alternatives.

Household characteristics such as age, family labor, marital status and sex are the explanatory variables which affect the adoption decision and these variables significantly differ among alternative *teff* technology adoption practices. i.e. 97.08 percent of $F_1I_0R_1$ and 97.05 percent of $F_1I_1R_0$ adopters where male headed households, while 94.94 percent of non-adopters were male headed). Additionally, 93.7 percent of $F_1I_0R_1$ and $F_1I_1R_0$ were married, and 90 percent of non-adopters were married. Furthermore, on average non-adopters were the oldest (44.72 years old) group. Further, non-adopters are less educated than (4 years of education) than adopters ($F_1I_0R_0$ is 4.5259 and $F_1I_0R_1$ is 5.583).

Total land holding, household asset and number of livestock are proxy variables, which are used to describe the economic status of the households. On average, non-adopters have the 2nd lowest land size (0.345 ha).Whereas, full technology adopters hold the highest land size (0.58 ha) followed by F_1I_0R1 adopters (0.49 ha). Full technology adopters have the highest asset holding (43,649.81birr) and highest number of livestock (25.26) followed by mixed technology adopters ($F_1I_0R_1$have asset of 2283birr and $F_1I_1R_o$ have asset of 3873birr) and $F_1I_1R_0$ have 17.16 livestock). Whereas, non-adopters have the lowest asset holding (1582.916 birr) and livestock ownership (13.28). This indicates that limited financial base of farmers could affect the adoption of modern technologies by constraining the initial investment and capital cost required (Mohammed, 2015).

Access to information and input are other factors which affect the adoption decision. As depicted in table 4.4, the average distance of non-adopters from the nearest input and output market is significantly higher than $F_1I_0R_0$, $F_1I_0R_1$, and $F_0I_1R_1$. Moreover, they have lower community meeting participation and frequency of DA visits. The proportion of non-adopter (48.31percent), who are member of cooperatives, is significantly lower than mixed technology adopters (71.22 percent of F1I1R0 and 59.12percent of F1I_0R1) were members of cooperatives.

Landholding and soil fertility are other factors which affect the adoption decision. These variables have significant difference among adopters and non-adopters. The proportion of full technology adopters' fertile land was found to be higher (54 percent) than that of non-adopters' and mixed technology adopters'. Whereas, the proportion of non-fertile soil plot is significantly higher (26.4) for non-adopters than adopters. Similarly, full technology adopters have higher land holding than other practices.

Table 4.4: statistical description of determinants of technology adoption Explanatory variables

	$F_0I_0R_0$		$F_1I_0R_0$		$F_1I_0R_1$		$F_1I_1R_0$		$F_1I_1R_1$	
	Mean (percent)	SD	mean	SD	mean	SD	Mean	SD	Mean	SD
Martial status	0.94***	0	0.939***	0.01	0.941	0	0.937***	0.01	1	0
education head	4.11***	6.156	4.5259***	6.26	5.5839***	6.889	4.469	5.7543	8.02	5.5159
Gender	0.949*** (94.94 percent)	0.27	0.952*** (95.27 percent)	0.27	0.97*** (97.08 percent)	0.16	0.97*** (97.05 percent)	0.16	1 (100 percent)	0
Age	44.72	13.30	46.53***	13.58	44.883**	11.509	44.37**	13.11	45.48***	12.094
Community meeting frequency	1.13***	2.54	2.57	3.72	2.89	3.554	2.788**	3.09	3.43***	2.985
Model farmer	1.75***	0.43	1.686***	0.46	1.496***	0.501	1.546***	0.498	1.215***	0.421
DA visit frequency	1.78***	1.62	2.35***	2.18	2.051	1.716	3.103***	4.48	5.1875***	5.814
Cooperative membership	1.51*** (48.31 percent)	0.50	1.4083 (59.16 percent)	0.49	1.408*** (59.12 percent)	0.493	1.28*** (71.22 percent)	0.425	1.09 (90.97 percent)	0.23
Distance to Asphalt	256.119***	154.75	215.15***	179.87	246.4015***	190.62	139.337***	165.56	163.65***	211.901

Distance to market(min)	98.117***	63.16	94.97***	71.41	89.81	62.62	65.8797	46.56	57.77	46.06
Distance to input market (min)	92.275***	61.75	72.46***	59.99	86.24***	66.77	54.07	45.162	50.93	42.73
plot distance	19.96	24.78	20.55	17.45	16.8905***	15.249	22.086	17.654	25.715**	23.302
Asset (birr)	1582.916***	2696.78	2929.915***	6835.759	2283***	2791.131	3873.306***	5855.587	43649.81**	185756
livestock	13.28612***	12.580	20.73	65.407	15.52***	10.22	17.16***	15.4432	25.36***	23.89
Family labor (day of man power)	14.0558	11.90	15.17	17.343	17.829**	14.06	15.2***	18.06	17.8	22.68
fertile soil)	0.314***	0.46	0.342**	0.47	0.37***	0.48	0.5***	0.5	0.54***	0.5
Moderate fertile	0.38***	0.418	0.444***	0.49	0.532***	0.5007	0.378**	0.485	0.38**	0.48
Soil	0.264***	0.442	0.209***	0.406	0.08***	0.283***	0.111**	0.009	0.08***	0.26
Farm size	0.345***	0.314	0.49***	0.46	0.45**	0.29	0.56	0.5263	0.58***	0.71

Note: Test used to compare the means of explanatory variables between non adopters ($F_0I_0R_0$) and adopters (each package of agricultural technology)
SD is standard deviation
* Denotes significance level at 10%
** Denotes significance level at 5%
*** Denotes significance level at 1%
Source: Own calculation

4.2 Econometrics' Result

In the first part of this section, the result of the multinomial logit selection model is discussed while; the second part dwells on the result of endogenous switching model. Different types of tests were undertaken to verify validity of the model. The Result of the wald test rejects the null hypostasis (i.e. all regression coefficients are jointly equal to zero) with $x^2(88) = 2282.46 : P > 0.00$. The Wald test result for the test of dependent category confirms that all alternative categories (5 alternative agricultural technology choices) are distinguishable with respect to the variables in the model as indicated in appendix 2. The Variance Inflation Factor (VIF) is also computed to test multicollinearity. The VIF result confirms that there is no multicollinearity across explanatory variables as indicated in table A1.

The multinomial endogenous switching regression (MESM) results show the significance of the mills ratio which indicates the existence of the endogenous self-selection problem. This verifies that using the MESM is the right choice. The falsification test for the overall significance of the instrumental variable is valid.[1]

4.2.1. Factors Determining the Adoption of Agricultural Technology

One of the objectives of this study is to evaluate the determinants of technology adoption in *Amhara* and *Oromia* regions specifically on *teff* production with a foucs on improved seed varieties, fertilizer and row planting. To do this, the multinomial logit selection model was applied; and the results are presented in table 4.5 below.

The reference or base category of the model is non-adopter ($F_0I_0H_0$), which is used to compare results of other agricultural technology practices. Considerable efforts have been made to include all theoretically important factors in the estimated model. Of these variables, only those found statistically significant, and to have a strong relation with adopting alternative agricultural technology are included for further discussion.

Human capital of the farmer is assumed to have a significant influence on the farmer's decision to adopt new technologies. Most adoption studies have attempted to measure human capital through

[1] Multinomial endogenous switching model use variables which affect the adoption decision but not the outcome equation as instrumental variable. g

the farmer's education, age, gender, and household size(Mwangi *etal*,2015).As table 4.5 shows these factors have a significant effect on adoption decision.

Age of farmers and adoption of $F_1I_1R_0$ has negative and significant (at 10 percent level of significance) relation. This could be because aged farmers are too reluctant and conservative to adopt new technologies. Whereas young farmers are better educated, less risk averse and they have more willingness to try new technology than old farmers. This result is in line with studies by Yu Bigxin*et al* (2011), Hailu *ea al*(201) and Gebreselassie *et al*(2015).

In developing countries like Ethiopia female headed households are not yet culturally developed and recognized. Accordingly, most female headed households are those who are either widowed or divorced. In such instances, beside the cultural factors, their probability of adopting fertilizer becomes negligible since male headed households have better access to information from extension agents and social network. Male headed households also have better access to resources like land, labor and other than female headed household (Hailu *etal*, 2014). As shown in table 4.5 being a male headed household have a positive and significant impact for adoption of $F_1I_0R_0$, $F_1I_1R_0$, and $F_1I_1R_1$. This confirms the results of Hailu *etal*, (2014)

The study result also shows that education is another factor which builds human resource. Education increases farmers' ability to obtain, process, and use information, which is relevant to the adoption decision. In addition to this, education makes farmers more open, rational and able to analyze the benefits of new technology. This in turn positively influences the adoption decision of the households. In relation to this Feder *et al*. (1985) argues that new technologies need skill; Hence, education increases the farmer's skill in that educated farmers are more likely to adopt new technology than uneducated ones. In line with this, education was found to have positive and significant (at 1 percent level of significance) effect relation with the adoption decision of $F_1I_1R_1$.This result is also in conformity with studies such as (Tamiru*et al* (2013) and Mekonnen, 2017).

Being a married household has negative and significant relation with $F_1I_0R_0$, $F_1I_0R_1$ and $F_1I_1R_0$ adoption; while, it has positive and significant relation with $F_1I_1R_1$ adoption. This was probably because the household head's adoption decision is influenced by his/her spouse's attitude and willingness toward technology, but unmarried households have freedom to decide what they want.

Literatures reveal that adoption of new technology is affected by the level of awareness of technologies (Mwangiand Kariuki, 2015). The current study considered distance of the household from the input and output market, access to extension service, contact with DAs', and community meeting as proxies for accessing knowledge of the available technology (i.e. improved seed varieties, fertilizer and row planting) and their characteristics.

Access of extension and DAs' services is formal sources of information about agricultural technology. Extension agents and DA's give detailed information about the source, use and importance of the modern inputs to the farmers (Ashnafie, 2006). Moreover, according to Sebsibiel *et al* (2014) agricultural extension service providers could influence the adoption decision by building human capital via training and advisory service and engaging in input distribution and farm credit. Besides, DAs' also function as a major channel between agricultural developments research outputs and small holder farmers. In line with this, access of extension service has positive and significant (at 5percent of significance level) impact on adoption of $F_1I_1R_0$. Similarly, the frequent DA visit has positive impact of the adoption of $F_1I_0R_0$, $F_1I_1R_0$ and $F_1I_1R_1$. This result is parallel with the study of Mekonnen (2017).

Farmers also get information about new technology from the community meeting. The result shows frequent community meeting has a positive and significant impact on adoption of $F_1I_0R_0$ and $F_1I_0R_1$. The result also supports the argument by Mwangi and Kariuki, (2015); i.e. community meeting increases social capital, trust, and idea and information exchange about new technology. Furthermore, farmers within a social group learn the benefits and usage of a new technology from each other. This in turn increases their like hood of adopting new technology. This relationship is expected and the result may show the importance of social capital and network of technology adoption.

Another variable that was found to affect the adoption decision is membership in cooperatives. The result shows that being a member of the cooperative has significant and positive impact on the adoption of $F_1I_0R_0$, $F_1I_1R_1$and $F_1I_1R_0$. It can be argued that the nature of the cooperative could directly influence other factors of adoption like credit, information, and access to training (Kolade and Harpham, 2014). Moreover, external finance agencies and governments prefer to deal with groups rather than individual farmers in the payment of loans and distribution of subsidized inputs.

Distance from the main road has a negative and significant effect on the adoption of $F_1I_0R_0$ and $F_1I_1R_0$. The result this study is supported by the argument of Sebsibiel *et al* (2015), that lower

access of infrastructure increases the production cost by increasing the cost of transport. As a result, farmers become less motivated to adopt agricultural technologies.

Distance from the output market holds the relation between access to market information and households' technology adoption. Furthermore, it contributes too easy to sell output and get pricing information. This makes the households more profitable and motivates for further production by adopting agricultural technology. In line with this, the current study revealed that distance to output market and adoption of $F_1I_1R_0$ and $F_1I_1R_1$ have negative and significant relation. This result is give confirmation for the study of Tamiru *et al*, (2013); Joachim *et al*, 2017 and Juma, (2013).

Distance to agricultural input dealers showed negative and significant relation with the adoption of $F_1I_0R_0$, and $F_1I_1R_0$. This could be mainly because as the farmer is far away from the input dealer the transportation cost to deliver inputs increases. This in turn increases the production cost (Senshaw *et al,* 2013). In addition to this distance to the input delivery institutions could also be taken as a proxy for distance to get information about the use and availability of modern agricultural inputs (Ashnafie, 2006). Hence, the distance to the input supplying institutions could be taken as a major obstacle for farmers to adopt fertilizer and improved seed in *Amhara* and *Oromia* region.

For developing countries like Ethiopia where there is limited access to credit, ownership of productive assets has considerable effect on the adoption decision since having an asset solves the liquidity constraint to buy agricultural technologies. In line with this, the study result shows having more asset significant (1 percent of significances) and positive relation with adoption of $F_1I_0R_0$, $F_1I_1R_0$, $F_1I_0R_1$ and $F_1I_1R_1$.

The result of the study has unexpected result on the relation between technology adoption decision and number of livestock as a result shows, number of live stocks owned by the households have a negative and significant impact on the adoption decision of all alternative technologies.

There is high demand of labor during the main farming season (summer) in Ethiopia. Ethiopia, farmers use their family labor as a main source of labor to pass this tough farming season. The current studies result indicates that family labor and adoption $F_1I_0R_1$, have positive and significant relation. In line with this Feder et al. (1985) argued that improved seed, high yield verity and row planting increases the seasonal labor demand further since these technologies are labor intensive. As a result having available family labor increase the likelihood of adopting labor intensive technologies' like row planting and fertilizer. The study result supports the result of Hailmaryam

*et a*l (2013) and Tigest (2014). Similar to this the study of Hicks and Johnson (1979) show that higher rural labor supply leads to greater adoption of labor intensive rice varieties in Taiwan. On contrary to this, the result of the study shows that family labor has a negative and significant impact on the adoption of $F_1I_0H_0$, which is unexpected result.

Fertility of land is another factor which determines the adoption decision of modern technology. By taking non-fertile land as a reference, soil fertility has a positive and significant effect on technology adoption decision. This may probably happen due to the risk aversion behavior of farmers. i.e. Farmers always incurred cost to buy agricultural technology as long as they expect higher return form new technology. But if they believe incurring cost for new technology could not bring higher return, they will not adopt new technology. In this case when the soil is fertile they have better confidence to be more productive and profitable; hence would adopt technology. But if the soil type is non-fertile they may loss, confidence of being profitable so they could make them less interest to adopt new technologies.

Production of agriculture could be increase either by expanding the area usage or adopting modern technologies. The former is not applicable to small farmers but the second option could be applicable. However household's technology preference depends on their farm size. As Adekambi ***et al*** **(2006)** argues small farmers prefer to use labor intensive and less risky technologies whereas large farmers prefer to use capital intensive and they can afford to assume risks. In line with this the current study result shows that farmers with small land size have negative and significant relation with adoption of $F_1I_0R_0$, $F_1I_1R_0$, $F_1I_0R_1$ and $F_1I_1R_1$. This result contradicts with previous studies Tigst, (2017) and Gebreselassie and *et al* (2014), which show that farm size positive and significant relation with adoption diction.

The last, but not the least, explanatory variable that determines technology adoption is parcel ownership. Having land certificate has negative and significant (10 percent level of significance) impact on the adoption of $F_1I_0R_1$. This is probably because when farmers are landless, they have an additional rental cost; as a result they want to minimize other input costs by employing new technology like row planting. But when the farmers have their own land, they may not be interested in this practice since they have no additional cost. This result contradicts with the study by Hailu and *et al* (2014).

Table 4.5: determinants of adoption of *teff* technology practice – multinomial logit method

Adopt	Adopt $F_1I_0R_0$		Adopt $F_1I_0R_1$		Adopt $F_1I_1R_0$		Adopt $F_1I_1R_0$	
	Coef.	Std.Err.	Coef.	Std.Err.	Coef.	Std.Err.	Coef.	Std.Err.
Age	0.002	0.005	-0.002	0.008	-0.009*	0.005	-0.007	0.01
Schooling	0	0.01	0.025	0.017	-0.015	0.011	0.061***	0.017
Sex dummy	0.677*	0.406	0.926	0.7	2.055***	0.531	13.391***	0.813
Marital status dummy	-0.698*	0.392	-1.461**	0.599	-1.458***	0.472	13.598***	0.868
Da visit for teff	0.077*	0.046	-0.014	0.065	0.17***	0.047	0.216***	0.051
Community meeting	0.049*	0.026	0.059*	0.034	0.001	0.027	-0.024	0.036
Corporate membership	0.272**	0.126	0.121	0.23	0.457***	0.138	1.447***	0.328
livestock	-0.005*	0.003	-0.012*	0.006	-0.013***	0.004	-0.01***	0.003
Distance to asphalt road	-0.002***	0	0	0.001	-0.003***	0	-0.001	0.001
Distance output market place	-0.001	0.001	-0.003	0.002	-0.007***	0.001	-0.008***	0.003
Distance input market	-0.002*	0.001	0.002	0.002	-0.004***	0.001	-0.001	0.003
Asset value	0**	0	0	0	0***	0	0***	0
Agriculture extension dummy	-0.192	0.157	0.47	0.308	0.519***	0.177	5.098	3.609
Family labor	-0.007**	0.003	0.009*	0.005	-0.002	0.004	0.01	0.006
Plot distance	0.005**	0.005	-0.02**	0.009	0.008	0.005	0.014**	0.006
Fertile soil	0.243	0.163	1.458***	0.406	1.1***	0.184	1.585***	0.391
Moderate Fertile soil	0.003	0.151	1.255***	0.394	0.384**	0.177	0.873**	0.395
Rain Water	1.617	0.395	2.054*	1.079	4.059***	1.131	1.931**	0.851
Farm size ha	-0.365	0.145	-0.664**	0.331	-0.352**	0.153	-1.12**	0.465
Model farmer	0.152	0.147	1.18***	0.232	0.465***	0.153	1.72***	0.295
Tenure	-0.041	0.143	-0.465*	0.245	-0.101	0.151	-0.321	0.238
_cons	-0.524	0.595	-3.982**	1.445	-3.617***	1.217	-37.939***	4.2

Model VCE= Robust; Number of observation =2830
SE is standard error
*Denotes Significance Level at 10%
**Denotes Significance Level at 5%
***Denotes Significance Level at 1%
Source: own estimate result

4.3 The Impact of Agricultural Technology on Productivity

Evaluating the economic implication of adopting a particular technology on productivity is the main objective of the study. There are some methods which are used to evaluate the impact of agricultural technologies on productivity; but OLS and comparison by actual mean are simplest and standard ways. If we use comparison of actual mean (indicated in appendix table A5), our conclusions drives to $F_1I_1R_1$and $F_1I_1R_0$ are more productive than other alternatives. Further, the productivity of $F_1I_0R_1$ is better than $F_1I_0R_0$ adopters. Besides, the unconditional average effect shows that the productivity of any agricultural technology practice ($F_1I_0R_0$, $F_1I_1R_0$, $F_1I_0R_1$ and $F_1I_1R_1$) adopters are more productive than non-adopters.

A second possible approach in estimating a linear regression model of productivity is that which includes binary variables equal to 1 if the farm household adopted a particular strategy (Table A3 of the appendix). This approach would lead us to conclude that farm households implementing $F_1I_1R_1$would be most productive, but adopting other alternative technology combinations makes farm households less productive.

However, both approaches can be misleading, and should not be implemented to evaluate the impact of agricultural technology adoption on the productivity of *teff*. Both methods assume that adopting agricultural technology is exogenously determined, while it is a potentially endogenous variable. The difference in productivity could be caused by unobservable characteristics of the farm households such as their skills. For instance, the apparently most successful farm households could also be the most skilled ones, and so, those that would have done better than the others even without adopting agricultural technologies. The current study addresses this issue by estimating a multinomial endogenous switching regression model as described in chapter 3: in a first stage, the researcher estimate the aforementioned multinomial logit model of choice between multiple combinations of strategies, and in a second stage, researcher estimates production function account for the endogenous strategy decision. Then, the study plug the coefficients of the productivity functions in equations (*m1-m6*) (see in appendix 6)to produce selection-corrected predictions of counterfactual productivity, that is what farm households would have earned if they had not adapted(Falco and Veronesi, (2013).

The true average adoption effect of adoption on productivity of plots is estimated based on the result of conditional average treatment effect. It is estimated by comparing their outcome variables

with their respective counterfactual; (i.e. the outcome variables of farm households who adopted at least one agricultural technology ($F_1R_1I_1$, $F_1R_1I_0$, $F_1R_0I_1$ and $F_1R_0I_0$) are compared with the outcome variables if the farm households had not adopted it). As table (4.6) indicates there is a significant difference between the outcome variables and counterfactuals. This implies that adopters of any combination of agricultural technologies are more productive than if they were non-adopter. The result shows that full technology adopters are more productive than single and mixed technology adopters. The highest productivity is obtained when the farmers adopt $F_1R_1I_1$ (1499 kg/ha) and $F_1I_1R_0$ (1222kg/ha). The second highest productivity of *teff* is 1061 kg/ha which is obtained when farmers adopt fertilizer. The lowest productivity is obtained when farmers adopt fertilizer and row planting ($F_1I_0R_1$). Although the technological intensity is higher for $F_1I_0R_1$ adopters, their productivity is lower than $F_1I_0R_0$.

Analyzing the average treatment effect of adoption of any agricultural technology on productivity is vital. Table (4.6) summarizes the expected productivity of *teff* under actual and counterfactual scenario. The difference in productivity of the actual and the counter factual scenario represents the true average treatment effect of adoption on *teff* productivity. According to the result the productivity of $F_1I_1R_1$, $F_1I_1R_0$, $F_1I_0R_1$, $F_1I_0R_0$ would be significantly reduced by 1.79 time less (664.4963kg/ha), 1.58 times less (450.4439 kg/ha), 1.35 time less (207.1006kg/ha) and 1.31 time less (252.605 kg/ha) respectively if they were non-adopters.

With regard to the ATU results of non-adopters, this study found that the productivity of non-adopters would significantly increased by 1.25 times more (199.4334 kg/ha), 1.357 times more (280.854 kg/ha) and 1.07 times more (57.1457 kg/ha) if they could have been adopted $F_1I_1R_1$, $F_1I_1R_0$, and $F_1I_0R_1$ respectively. This result shows that the productivity of non-adopters could enhance by adopting mixed and full agricultural technology. But adopting fertilizer would not have a significant change on productivity of non-adopters..

The base heterogeneity (BH (A1)) and (BH (B1)) result shows that there is heterogeneity among adopters and non-adopters that makes adopters more productive than non-adopters were they have similar technology treatments. For instance the negative value of base heterogeneity of all alternative agricultural technology practice for non-adopter (BH (A1)) imply that adopters will be more productive than actual non-adopters in the absence of technology and the negative value

of (BH(B1)) indicates that non-adopters will be the least productive than the actual adopters if they venture in to adopters.

On the other hand the average treatment effect of $F_1I_0R_0$ adopters shows that, the productivity of $F_1I_0R_1$ productivity would significantly increased by 76.76 if they could have adopted $F_1I_0R_0$. But the productivity of $F_1I_1R_0$ and $F_1I_1R_1$, decreased by 110.949 kg/ha and 236.425 kg/ha respectively if they have been adopter of $F_1I_0R_0$.

With regard to the ATU for $F_1I_0R_0$ adopters result, the productivity of $F_1I_0R_0$would significantly increase if they could have been the adopters of $F_1I_1R_0$ by 190.269 kg/ha and $F_1I_1R_1$ by 156.93kg/ha. This implies that the productivity of fertilizer adopters could further increase by adopting $F_1I_1R_0$ and $F_1I_1R_1$.

Furthermore, the base heterogeneity effect BH(2A) & BH(2B) shows that there is unobserved factors which make full and mixed technology adopters more efficient on the technology utilization than non-adopters. For example BH(2A) result shows that the productivity of $F_1I_1R_0$ and $F_1I_1R_1$ could be higher than actual fertilizer adopters if they were fertilizer adopters and BH(2B) shows that the productivity of $F_1I_0R_0$ is significantly lower than $F_1I_1R_1$ adopters if they were full technology adopters.

Adopting $F_1I_0R_1$ is another alternative choice; the productivity of this group could significantly increase if they could have adopted $F_1I_0R_0$, $F_1I_1R_0$ and $F_1I_1R_1$ by 76.76 kg/ha, 248.25kg/ha and 352.62 kg/ha. Besides the result of ATT shows that, the productivity of $F_1I_1R_0$would significantly increased by 221.52 and the productivity of $F_0I_0R_0$ significantly increased by 57.14 kg/ha if they could have been adopters of $F_1I_0R_1$. But for $F_1I_0R_0$ and $F_1I_1R_1$ adopters, being $F_1I_0R_1$ adopters have no significant difference on their productivity.

The result of BH(3A) implies that the productivity of $F_1I_1R_0$ and $F_1I_1R_1$would have been significantly higher than the productively of $F_1I_0R_1$ but the productivity of $F_0I_0R_0$ would have been lower than$F_1I_0R_1$ if all groups adopt $F_1I_0R_1$. This may indicate the existence of some source of heterogeneity that makes full adopters and $F_1I_1R_0$ more efficient producers than $F_1I_0R_1$ under similar scenario.

The ATT of $F_1I_1R_0$ shows that the productivity of all alternative technology adopters except $F_1I_1R_1$ would significantly increased if they could have adopted $F_1I_1R_0$ .As table 4.6 stated the productivity of this groups could significantly increase by 167.84 kg/ha if they could have been full technology adopters, were as their productivity would decreased if they could have been other alternatives technology adopters'($F_0I_0R_0$, $F_1I_0R_0$and F_1I_0-R_1).

The base hetroginity BH(4A) shows that that the productivity of $F_1I_1R_0$ is significantly higher than the productivity of $F_0I_0R_0$ if both groups were $F_1I_1R_0$ adopters but the productivity of $F_1I_1R_0$ is lower than the productivity of $F_1I_1R_1$, when both groups were $F_1I_1R_0$ adopters. The base heterogeneity BH(4B) shows that $F_1I_1R_0$ adopters are more productive than non-adopters with the absence of technology treatments but the productivity of this group is less productive than full technology adopters in a condition were both groups are full technology adopters. This shows that there is heterogeneity among $F_1I_1R_0$ adopters and other groups which make $F_1I_1R_0$ adopters less efficient than full adopters and make $F_1I_1R_0$ more efficient than other groups.

The result of ATT of $F_1I_1R_1$, shows the productivity of other adopters would have increased if they could have been full technology adopters. Furthermore full technology adopters would have lowered productive if they could have been other alternative technologies adopters except $F_1I_0R_1$, which would have shown insignificance productivity difference.

The base heterogeneity BH(5B) result indicates that full technology adopters($F_1I_1R_1$) under counter factual setting of adopting any of alternative agricultural technology they would have been more productive than $F_0I_0R_0$,$F_1I_0R_0$, $F_1I_0R_1$ and $F_1I_1R_0$.Besides (BH5A) shows that full technology adopters are still the highest productive in a condition were other adopters adopt full technology. This indicates that there is heterogeneity among full technology adopters and other alternative packages which make full adopters more efficient utilizers of technology than others.

Transitional heterogeneity effect for TH1 is negative which indicates that non adopters would be lower productive than adopters if they adopters become non-adopter and non-adopters became adopter.

Positive value of TH (5) shows that full adopters would have been more productive than non-adopters, if they venture to non-adopter and if non-adopters became adopters.

Table 4.6: conditional average effects of adoption of *teff* technology

Sub sample	Decision strategy				
	To adopt				Not To adopt
	$F_1I_0R_0$	$F_1I_0R_1$	$F_1I_1R_0$	$F_1I_1R_1$	
Non adopter house hold	799.8364[1]	843.6167[1]	1067.325[1]	985.9044[1]	786.471
TT	-252.605***	-206.8275***	-450.4439***	-64.4963***	
TU	-13.3654	57.1457***	280.854***	199.4334***	
TH(1)	-239.2396	-263.973	-731.2979	-863.9297	
Farm house holds who only adopt fertilizer	1061.92	1052.99[2]	1252.189[2]	1218.85[2]	809.315[2]
TT		76.76***	-110.9495***	-236.425***	13.3658
TU		-8.93	189.269***	156.93***	-252.605**
TH (2)		85.697	-113.502	-393.359	265.9708
Farm house holds who adopt fertilizer and row planting	1090.906[3] (K)	1014.139 (L)	1262.39[3] (M)	1366.764[3] (N)	807.3115[3] (O)
TT	-8.98		221.52***	69.93	57.14***
TU	76.76**		248.25***	352.62***	-206.8275***
TH (3)	1099.886		-326.25	422.55	264.106
Farm house holds who adopt fertilizer and improved seed	1111.692[4] (Q)	1444.162[4] (R)	1222.642 (S)	1429.5577[4] (T)	772.1981 (U)
TT	156.93***	352.625***		167.843***	199.43***
TU	-110.94***	-221.52		206.915	-450.444
TH4	-79.4944	422.56013		39.0687	731.2979

Full technology adopters	1262.715[5]	1569.008[5]	1331.297[5]	1499.14	834.6437[5]
TT	157.85	352.625***	206.92		199.43
TU	-236.425***	69.8679***	-167.843		-664.496
TH5	394.275	485.001	276.498		730.6694

	BH(A1)	BH(A2)	BH(A3)	BH(A4)	BH(A5)
$F_0I_0R_0$		262.084***	170.52***	155.322***	513.094***
$F_1I_0R_0$	-20.84		-38.796	-29.543	280.145***
$F_1I_1R_0$	-20.56	29.544***			69.58***
$F_1I_1R_1$	14.27	49.544***	-430.02***	-108.65***	
$F_1I_1R_1$	-48.17	-200.80***	-554.94***	-69.58	

	BH(B1)	BH(B2)	BH(B3)	BH(B4)	BH(B4)	BH(B5)
$F_0I_0R_0$		22.84	20.567***		-14.27***	48.173***
$F_1I_0R_0$	-262.0836		28.988		49.77***	200.79***
$F_1I_0R_1$	-170.5225***	38.831			430.023***	555.86***
$F_1I_1R_0$	-155.317***	29.5446	39.74			108.66**
$F_1I_1R_1$	-513.23***	-280.29	-132.24		69.5823	

Note: $F_1I_1R_1$, $F_1I_1R_0$, $F_1I_0R_1$, $F_1I_1R_1$, and $F_0\ I_0\ R_0$ are actual values were as $F_1I_1R_1^{1}$, $F_1I_1R_0^{2}$, $F_1I_0R_1^{3}$, $F_1I_1\ R_1^{4}$, and $F_0\ I_0\ R_0^{5}$ are counter factual.

BH(A1) base heterogeneity effect for non-adopters, BH(B1) base hetroginity effect for adopters
BH(A2) base heterogeneity effect when other alternative technology adopters become fertilizer adopters, BH(B2) base hetroginity effect when $F_1I_0R_0$ adopters become other alternative technology adopters
BH(A3) base heterogeneity when other technology adopters adopt become $F_1I_0R_1$, BH(B3) base heterogeneity effect when $F_1I_0R_1$ adopters adopt become other technology adopters
BH(A4) base heterogeneity when other technology adopters adopt $F_1I_1R_0$, BH(B4) base heterogeneity effect when $F_1I_1R_0$ adopters adopt other technology.
BH(A5) base heterogeneity when other technology adopters adopt $F_1I_1R_1$, BH(B5) base heterogeneity effect when $F_1I_1R_1$ adopters adopt other technology.
TH(1) is transitional heterogeneity effect between non-adopters and adopters .
TH(2) is transitional heterogeneity effect between fertilizer adopters and other alternative technology adopters.
TH(3) is transitional heterogeneity effect between fertilizer adopters and improved seed adopter($F_1\ I_1\ R_0$) and other alternative technology adopters
TH(4) is transitional heterogeneity effect between fertilizer adopters and row planting adopter($F_1\ I_1\ R_0$) and other alternative technology adopters .
TH(5) is transitional heterogeneity effect between full technology adopter($F_1\ I_1\ R_0$) and other alternative technology adopters.

* Denotes significance level at 10 percent

** Denotes significance level at 5 percent

*** Denotes significance level at 1 percent

Source: Own result (estimation)

Chapter Five

Conclusion and Policy Recommendation

5.1. Conclusion

For a country like Ethiopia where persistent food insecurity and severe poverty is the main agenda for the government, enhancing productivity of agriculture is taken as a major solution. Therefore this study focuses on studying the productivity of teff, which is one of the main cereal crops in the country, in *Amhara* and *Oromia* regions. An improvement in the productivity of teff could contribute in achieving and reducing poverty because it is produced by around 4 million households and it is a staple food both in rural and urban areas of the country. The productivity of teff could be achieved either by increasing the rate of adoption of technologies or by improving the technical efficiency of teff. This study gives a focus for the former specifically on the adoption of row planting, improved seed and fertilizer. Prior research focuses on the impacts of specific practices on productivity of teff, but there is less information on simultaneous adoption of agriculture technologies (i.e. fertilizer, improved seed & row planting) and their impacts on productivity of teff as a whole.

The study analyzes the determinants of adoption of multiple agricultural technologies and their impact on productivity of teff by using EDRIs' teff value chain data which is collected from five zones (East *Gojjam*, West *Gojjam*, South Shoa, West Shoa and South West Shoa) from 1200 households. To achieve the objectives of the study, a multinomial endogenous switching regression model of agricultural technology adoption and productivity is estimated. This method is based on a counterfactual analysis, and also accounts for heterogeneity in the decision to adopt or not in a particular strategy, and for unobservable characteristics of farmers and their farm.

The multinomial logit selection model result revealed that the agricultural technology adoption decision is influenced by observable plot characteristic, household and institutional characteristics. More specifically, the agriculture technology adoption decision is positively related access to rain water, fertile soil, community meeting, being member of cooperative, education and family labor. Whereas adoption of agricultural technology have negative relation with distance from the plot to

home; home distance (from the nearest village market, asphalt and nearest input dealer), land ownership, farm size and age of the house hold head.

The result of endogenous regression shows that, Adoption is more effective when it is used as a combination of agricultural technologies than single agricultural technologies. More specifically, the result shows that, adopters of any teff technology on average are more productive than non-adopters. Adopting full teff package provides higher productivity of teff than adopting single or combined technologies. In addition, adopting $F_1I_1R_0$ (fertilizer and improved seed adopter) make farmers more productive than adopting $F_1I_0R_0$ (fertilizer adoption).

Generally, in conclusion, some caveats have to be taken as important. The study is relayed on cross section and plot data, which could not show the time dimension impact of adoption of teff technologies. In reality some adoption strategies can be effective in short time while others may deliver payoff in the long run. As a result, it is better if future researchers use panel data with time dimension to analyze the impact of adoption on a given outcome variable, including the productivity of teff.

5.2 Policy Recommendation

The findings of this study are particularly important to design policies for effective promotion of Individual as well as combinations (packages) of agriculture technology adoption in order to enhance the productivity of *teff* in Amhara and Oromia regions. Single or combinations of Technology adoption enhance the productivity of *teff* producer farm house holds. Hence, this study draws the following policy implications to enhance the productivity of agriculture sector

- Having information about agriculture technology increases the adoption decision of multiple and single agricultural technologies. Thus the Government should increase the access of information by increasing the access of quality extension service to increase the information dissimilation.
- Distance from the asphalt and market increase the agriculture technology adoption decision. Thus the government should increase the access of infrastructure.
- Being a women household head decrease the adoption of agriculture technology. Therefore the government should give especial focus on empowering female by giving especial treatment like especial extension service, facilitating especial loan which is easily accessible for women to increase the adoption of agricultural technologies.

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Appendix

Table 1(A1). Test for multicollnitrty by VIF

Variable	VIF	1/VIF
Da visit	3.22	0.310945
Soil quality 1	2.19	0.457107
Soil quality 2	2.14	0.467586
Sex	1.8	0.555151
Marital status	1.79	0.559054
Farm size	1.43	0.697734
Labor	1.42	0.70561
Family labor	1.38	0.724634
Nearest input market	1.37	0.728467
Nearest output market	1.32	0.7551
Number of livestock	1.23	0.810585
Nearest asphalt	1.22	0.817362
Model farmer	1.2	0.83078
Fertilizer	1.2	0.833795
Community meeting	1.18	0.846043
Seed	1.17	0.852998
Cooperative membership	1.17	0.856814
Herbicide	1.14	0.878144
Age	1.14	0.879157
Tuner	1.13	0.882698
Row planting	1.09	0.916392
Asset value	1.06	0.947567
Schooling head	1.05	0.950107
Plot distance	1.04	0.958555
Water source	1.03	0.974489

Mean VIF	1.46	

Table A2. Test for IIA (Test for dependent categories**)**

Categories	chi2	df	P>chi2
Agriculture technology $F_OI_0R_0$ with agriculture technology $F_1I_0R_0$	122.31	22	0
Agricultural technology $F_0I_0R_0$ with agricultural technology $F_1I_0R_1$	117.967	22	0
Agricultural technology $F_0I_0R_0$ with agricultural technology $F_1I_1R_0$	304.135	22	0
Agricultural technology $F_0I_0R_0$ with agricultural technology $F_1I_1R_1$	1512.556	22	0
Agricultural technology $F_1I_0R_0$ with agricultural technology $F_1I_0R_1$	165.507	23	0
Agricultural technology $F_1I_0R_0$ with agricultural technology $F_1I_1R_0$	265.94	23	0
Agricultural technology $F_1I_0R_0$ with agricultural technology $F_1I_0R_1$	1550.184	23	0
Agricultural technology $F_1I_0R_1$ with agricultural technology $F_1I_1R_0$	161.166	23	0
Agricultural technology $F_1I_0R_1$ with agricultural technology $F_1I_1R_1$	1137.423	23	0
Agricultural technology $F_1I_1R_0$ with agricultural technology $F_1I_1R_1$	1510.49	23	0

Note: HO: All coefficients except intercepts associated with given pair of outcomes are equal to zero (i.e., categories can be collapsed)
Source: Stata output

Table A3 OLS Estimates of productivity equation for Pooled Sample

Productivity	Std. Err.	t	P>t
Row planning and fertilizer	-88.9138	57.09377	-1.56
Fertilizer and seed	96.89226	26.75191	3.62
Full adopters	294.3293	78.41283	3.75
Total fertilizer /ha	1.416922	0.168574	8.41
Herbicide/ ha	0.162902	0.198474	0.82
Seed/ha	1.74151	1.18281	1.47
Labor	0.733558	0.123313	5.95
Rain water source	3.124409	108.0289	0.03
Fertile	315.1166	32.82518	9.6
Moderate fertile	147.8193	32.43113	4.56
Farm size	-129.68	18.87974	-6.87
Livestock	0.438048	0.251135	1.74
Schooling head	4.000617	1.837179	2.18
Sex	218.5971	59.40851	3.68
Age	-2.70075	0.843047	-3.2
_cons	509.4063	139.2928	3.66

Note: Adjusted $R2 = 0.345$. Sample size: 2,800

TABLE A4. Parameter Estimates – Test on the Validity of the Selection Instruments

Productivity of non-adopters	Coef.	Std. Err.	t
Herbicide /ha	1.64864	0.418774	3.94
Seed/ha	2.15219	2.309975	0.93
Livestock	4.916789	1.436379	3.42
Labor/ha	0.31131	0.237316	1.31
Rain water	103.4229	109.3205	0.95
fertile	250.2304	55.70475	4.49
Moderate fertile	104.3073	52.55447	1.98
Farm size	-65.8474	33.04824	-1.99
Schooling head	-3.34198	3.259167	-1.03
Sex	85.54291	98.31866	0.87
Age	-1.39475	1.615265	-0.86
IV variables			
Da frequent meeting	-0.26583	10.29382	-0.03
Community meeting	5.905339	7.006912	0.84
Cooperative membership	-47.1452	43.61822	-1.08
Distance asphalt road	0.248382	0.119084	2.09
Distance to output market	0.362503	0.325714	1.11
Distance to input market	0.027648	0.357428	0.08
Asset value	1.38E-06	7.13E-06	0.19

Walking distance	0.243483	1.139968	0.21
Model farmer dummy	-78.7599	49.12173	-1.6
Tenure	-26.6583	49.67517	-0.54
extension visit	19.12217	49.73997	0.38
_cons	274.5707	214.9587	1.28

Wald test on instrumental variables (F-stat.) 0.2373

Sample size 426

Adjusted *R*2 0.1508

Note: Robust standard errors in parentheses.

Table A5: mean of unconditional *teff* productivity in alternative technology choice

Variable	Mean	Std. Dev.
non-adopter	795.5142kg/ha	266.1469
single	1056.294 kg/ha	266.2989
fertilizer& improved seed adopter	1110.241 kg/ha	615.1576
fertilizer and row planting adopters	1196.171 kg/ha	261.6432
Full adopter	1258.857 kg/ha	783.1552

Table A6 : Endogenous Swiching Model Result

Variables	Yield/Ha $F_0i_0r_0$	Yield/Ha $F_1i_0r_0$	Yield/Ha $F_1i_0r_1$	Yield/Ha $F_1i_1r_0$	Yield/Ha $F_1i_1r_1$
Herbicide/Ha	1.744***	-0.099	1.685	0.186	-1.876
	(0.261)	(0.239)	(1.724)	(0.527)	(1.569)
Seed/Ha	1.844	-1.656	-9.860***	6.882***	7.354
	(3.639)	(1.814)	(1.909)	(1.381)	(4.494)
Number Of Live Stock	3.831***	0.335	3.742	-1.938	-3.840
	(1.215)	(0.242)	(8.007)	(2.002)	(5.881)
Labor/Ha	0.259	1.632***	0.508	0.632**	-0.202
	(0.269)	(0.333)	(0.955)	(0.260)	(0.177)
Rain Water=1	193.252	-369.441	222.165	831.838	-935.223
	(119.679)	(233.795)	(179.973)	(547.799)	(857.937)
Fertile Plot =1	302.568***	232.566**	-183.483	637.361***	244.687
	(85.714)	(94.264)	(275.788)	(73.191)	(358.364)
Moderate Fertile Plot=1	119.185	155.680**	-395.832	366.527***	-256.418
	(72.470)	(66.840)	(253.011)	(64.633)	(304.999)
Farm Size	-53.978**	-176.250***	-32.607	-96.629**	-44.895
	(26.880)	(37.981)	(65.760)	(42.927)	(189.141)
Live Stock	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Education Of Head	-5.381*	7.356	16.864*	-5.909	-50.840**
	(3.206)	(4.531)	(9.008)	(7.732)	(24.769)
Gender	163.995***	116.227**	79.434	508.232***	0.000
	(51.562)	(49.682)	(328.772)	(158.284)	(0.000)
Age	-2.699***	-2.214***	-6.881***	-4.391*	-2.314
	(0.760)	(0.746)	(2.500)	(2.300)	(8.537)
M1		243.655*	338.892	812.940*	1,006.434
		(127.748)	(407.449)	(425.814)	(1,629.306)
M2	-405.487		392.504	-1,083.369***	43.189
	(263.226)		(485.116)	(329.969)	(1,545.266)
M3	-189.882***	224.772		439.864	-1,596.006
	(65.501)	(215.604)		(313.854)	(1,184.734)
M4	500.430**	-81.626	41.227		602.371
	(242.093)	(207.316)	(182.010)		(930.124)
M5	34.799	-294.144	-817.890*	-532.139*	2122002.648

	(355.775)	(329.043)	(445.705)	(306.281)	(2771427.152)
Sigma2	506,007.976***	363,502.444***	658,478.946	2044449.113***	0.886
	(242,383.161)	(109,846.233)	(657,329.730)	(786,725.643)	(0.886)
Rho1		0.518***	0.536	0.729**	0.038
		(0.201)	(0.561)	(0.301)	(0.688)
Rho2	-0.731*		0.620	-0.972***	-1.405**
	(0.428)		(0.416)	(0.167)	(0.604)
Rho3	-0.342***	0.478		0.395	0.530
	(0.132)	(0.425)		(0.424)	(0.546)
Rho4	0.902***	-0.174	0.065		
	(0.296)	(0.389)	(0.332)		
Rho5	0.063	-0.626	-1.293*	-0.477	3,379.800***
	(0.629)	(0.574)	(0.681)	(0.405)	(842.951)
Constant	88.352	1,394.546***	1,560.835***	-1,309.966**	
	(354.832)	(307.625)	(545.176)	(543.810)	
Observations 2800	.				
Standard Errors In Parentheses					

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Declaration

I declared this thesis is my original work and it was done in collaboration with my advisors. All sources of materials that used for this thesis have been dully acknowledged.

Declared by:
Name: Etsehiwot Semreab

Signature: _____

Date: _____

As thesis advisor, I hereby confirm that this thesis is the output of research undertaken by Etsehiwot Semreab under my supervision and that it be submitted for the M.Sc. degree award.

Confirmed by Advisor: **Hailu Elias (PhD)**

Signature: _____

Date: _____

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June, 2018