An Economic Analysis of Farmers' Risk Attitudes and Farm Households' Responses to Rainfall Risk in Tigray Northern Ethiopia

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Key words: rainfall risk, ex-ante risk management, ex-post risk coping strategies, off-farm labor supply, fertilizer adoption, Northern Ethiopia, Tigray.

Dedicated to the memory of

my late father

Haile Abreha Gebrewahid

And my late brother

Gebreegziabher Haile Abreha

Abstract

Rural households in semi-arid areas often experience rainfall-related shocks that result in low and uncertain income. Household's survival depends on the ability to anticipate and to cope with this uncertain income. Through time, households have developed ex-ante risk management and ex-post risk coping strategies. These include crop portfolio adjustments and off-farm activity diversification. This thesis investigates the role of rainfall and rainfall risk on households' risk management and risk coping strategies. Econometric models based on the neo-classical household production and consumption model were used. These methods were applied to a four-year (1996, 1997, 2001, and 2002) panel data sample of Tigray (Northern Ethiopia) farm households.

The study showed that farmers' ex-ante strategic response to rainfall risk is through diversification of crops to be grown. Choosing the crops most suited to specific rainfall conditions was proven to be a strategy of farmers to cope with unpredictable rainfall. In times of low rainfall, the dominant crops to be chosen are teff and grass pea. Rainfall risk also increases the probability of off-farm labor supply. Therefore, households' off-farm labor supply can be seen as an ex-ante and ex-post income smoothing strategy. Moreover, this study showed that ex-post consumption variability and rainfall risk negatively correlated with ex-ante fertilizer adoption decisions. This implies that households are biased toward technologies that are less risky. This leads to the conclusion that any mechanism that allows farmers to smooth consumption ex-post will raise ex-ante fertilizer adoption.

Ex-ante crop choice, fertilizer adoption, and reliable water availability for farming can be viewed as complements. These complementarities suggest that policies that focus on rainwater harvesting techniques and promoting small-scale irrigation would promote fertilizer adoption. Reducing rainfall-induced risk leads to more fertilizer use, and therefore, to more production and income. Expansion of off-farm employment opportunities inside and outside agriculture would also improve households' risk management and risk coping capacities.

Keywords: rainfall risk, ex-ante risk management, ex-post risk coping strategies, off-farm labor supply, fertilizer adoption, Northern Ethiopia, Tigray.

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Chapter 1
General Introduction

1.1 Background

Knowledge of how subsistence farm households make economic decisions under risk is important in determining strategies and formulating policies for agricultural development. The economic environment is characterized by a high degree of risk and uncertainty caused by erratic rainfall, poorly functioning or missing markets, pests and diseases and poor health situation. Risk and uncertainty impact households' production and consumption decisions. There is strong evidence that poor farm households are risk-averse (Moscardi and de Janvry, 1977; Dillion and Scandizzo, 1978; Binswanger, 1980, 1981, 1982; Antle, 1983, 1987). These general conclusions and observations have stimulated considerable research into the effects of risk on farmers' economic decisions. Some studies have focused on production decisions and choice of technology (Wolgin, 1975). Other studies have analyzed risk coping and risk management strategies (Udry, 1990, 1994; Townsend, 1994), or use of assets or savings to cope with risk (Udry, 1995; Dercon 1996).[1]

Under conditions where insurance and credit markets are incomplete or do not exist, and household savings are too little to cope the risk, the only mechanisms left are to increase family labor supply to the wage market and/or to use conservative crop production methods ex-ante. In dealing with crop income variability, the first priority is to avoid drops in consumption below the minimum level, and only secondary to smooth income. It has also been pointed out that rural households use income diversification to manage and mitigate risk (Ellis, 1998).

Households ex-ante and ex-post responses to risk have been studied extensively (Dercon and Krishnan, 2003; Barrett *et al*., 2002; Dercon, 2002; Morduch, 2002; Udry, 1990, 1994 and Townsend 1994).[2] These works generally focus on the effectiveness of public safety nets and financial markets on enhancing households' ability to deal with risk. Moreover, the objective is to look into the extent to which public safety nets and financial intermediation help to smooth consumption. Safety net and food for work programs have a problem of targeting the poor and they remain largely relief programs in response to emergencies (Barrett *et al*., 2002).

In the absence of credit and insurance markets, such financial strategies are typically weak or insufficient, and they represent only one element of households' responses to risk. Moreover in

[1] Choice under risk occurs when the probability distribution of the outcomes are objectively known to the decision maker. Choice under uncertainty occurs when no objective probability distribution is given to the agent.
[2] For the classification of households' ex-ante and ex-post responses to risk see Alderman and Paxson (1994).

a resource poor area like Tigray, Northern Ethiopia, financial strategies have little importance. A possibly more important strategy is households' effort to diversify economic activities before shocks occur, or to re-adjust labor supply decisions after a shock has occurred. Here the importance of the presence and well functioning of a labor market is significant given that labor is the principal asset owned by the poor.

Kochar (1999) argues that labor supply readjustments rather than asset or financial strategies are the main strategy used by rural households in India to cope with negative farm income shocks. The study demonstrates that over three-quarters of households increased labor supply to the wage market following a shock to their farm production. Dercon (1998) discusses the importance of activity diversification in managing risk. Similarly, Rose (2001) provides evidence on ex-ante and ex-post response to risk finding that in response to large rainfall variability households are more likely to participate in off-farm employment in India. Kurosaki and Fafchamps (2002) examined farmers' crop choices (ex-ante) in the presence of price and yield risk in Punjab, Pakistan. They found that even in well-developed markets, crop choices are dependent on risk. Empirical evidence is still lacking on how households respond to rainfall shocks in non-dynamic and subsistence agricultural environments in contrast to more dynamic rural settings. In areas, where drought is a common phenomenon, particularly in Northern Ethiopia, it will be of interest to investigate how households respond to rainfall shocks. Thus, this study will focus on modeling of risk decision behavior of farmers in Tigray, Northern Ethiopia. Particularly, the focus of this research will be on identifying farmers risk behavior and their ex-ante and ex-post management of rainfall-induced risk. This will help to identify the opportunities and constraints faced by the rural households in the process of maintaining smooth income and smooth consumption. Moreover, it would also help in determining appropriate risk management policies.

1.2. Problem Statement

A distinctive feature of life in semi-arid Africa is the importance of risk. This is immediately apparent for those who depend upon farming for their livelihoods. Differences in timing, intensity and amount of rainfall and the incidence of diseases and pests cause farm income to fluctuate unpredictably. Risk not only affects crop income, it has an indirect effect on off-farm income as well.

The poorest households are concerned primarily with downward income fluctuations because they are difficult to cope with. Given the type and amount of land the poorest households farm, they are most at risk from natural disasters such as drought. The poorest tend to live furthest away from health facilities and in areas with poor infrastructure. Weak health and bad nutrition also make increasing labor supply to other farms and to the wage market difficult. In such situations, households face extreme unfavorable trade-offs. They must engage in short term responses which provide an immediate gain in income and consumption smoothing, but at a very high long term cost which hinders development prospects. These are the situations which lead them to choose low cost low return production techniques.

In Northern Ethiopia, agriculture is rain-fed and yields not only vary from one year to the next, but also between different households in the same village. The farm households do not want to undergo the consequences of risk that is to allow high variability in consumption. To attain this objective households have developed a variety of mechanisms for coping with risk. This includes risk management and risk-coping strategies. These underscore the multitude of risk and the important effects it has on the lives of rural households in Northern Ethiopia.

Rural farmers' current circumstances reflect the cumulative challenges faced by the country over the past decades. In particular, the country is extremely vulnerable to drought and since the early 1980s, has experienced seven major droughts, five of which resulted in famines. The most recent drought, which occurred in 2002/2003, affected approximately 13 million people (MOFED, 2005). In addition to climatic factors, the country has suffered under the misguided economic policies of the socialist Dergue regime, which ruled from 1974 to 1991.[3] Since the Ethiopian Peoples' Revolutionary Democratic Front (EPRDF) replaced the Dergue in 1991 a number of market-oriented reforms have been implemented. For example, the country liberalized its foreign exchange markets and decentralized the public administration to the woreda (district) level. In rural areas, grain markets were liberalized and fertilizer markets were opened up to participation from the private sector. In the mid 1990s, the EPRDF also established the Agricultural Development Led Industrialization Strategy (ADLI), which emphasizes the role of the agricultural sector as a catalyst for immediate improvements in food security and for long-term growth in the broader economy. However, the outbreak of conflict with Eritrea between 1998 and 2000 created a humanitarian emergency in the northern part of Ethiopia and reduced the availability of resources to finance many of these reforms.

Meanwhile, with the return to peace, the government has reaffirmed its commitment to generating growth and reducing poverty, especially through a strong focus on the agricultural and rural sector. Since more than 85 percent of the country's population lives in rural areas where

[3] In this period, the rural economy was largely ignored and heavily taxed. Forced labor on community development projects was determined by the state. It also included forced delivery to a corporation called the Agricultural Marketing Corporation, of a specified quota of grain. Hence in these periods, famine and war had not only created a big humanitarian disaster, but also pushed the economy further back (Dercon, 1997).

agriculture is the main economic activity and where the poverty ratio is very high, and since the nonagricultural sector is extremely small in Ethiopia, any strategy for increasing rural incomes has to focus on generating rapid growth in the agricultural sector. To this end, the Ethiopian government has not only continued to support the ADLI Strategy but has also launched a series of development and poverty reduction programs, such as the Sustainable Development and Poverty Reduction Program (SDPRP) in 2002 and the Food Security Strategy in 2002, and the Plan for Accelerated and Sustained Development to End Poverty (PASDEP) in 2005, which is a guiding strategic framework for the five year period 2005-2010. Agricultural growth, food security, and accelerated rural development are the cornerstones for all these programs.[4]

The Food Security Strategy is basically derived from the country's rural development policy. It aims at increasing domestic food production; ensuring access to food for food deficit households and strengthening emergency response capabilities. It is recognized that land, labor, soil, and water are the main asset base of both the farming community and economy of the country, without which the achievement of food security is unlikely. Land and labor based agricultural development is considered as the main strategy. It has also given due attention to the problems of erratic rainfall. Accordingly, water harvesting and proper utilization are identified as the top priority areas of intervention. These help to combat harvest failures.

Although, structural transformations are important in the long term, more immediate gains in poor households' welfare can be achieved through proper and better understanding of the farm household economic decisions and knowing their attitudes towards risk. Knowing the behavior of farmers would enable policy makers to devise policies that can overcome some of the critical constraints they now face in meeting their basic needs. To this end this study focused on understanding the decision behavior of farmers' and households' ex-ante and ex-post management of rainfall-induced risk.

1.3 Research objective

It is important for policy makers to understand how rural households respond to risk. Households' crop choice and labor supply behavior have important implications for their ability to smooth consumption during income shocks. Tigray (Northern Ethiopia) presents a good example of households facing and adapting to risk due to high variability in rainfall. The

[4] A household is food secure if it can reliably gain access to food in sufficient quantity and quality for all household members to enjoy a healthy and active life (FAO, 1998)

objective of the study is, therefore, to examine farmers' attitudes toward risk, and to analyze ex-ante and ex-post responses to risk. Specifically, this research intends to:

1. examine the decision behavior of farm households under risk;
2. examine the impact of rainfall risk and household socio-economic conditions, on crop choice;
3. analyze the effect of rainfall on farm households' off-farm labor supply;
4. analyze the effect of rainfall on ex-post consumption and ex-ante fertilizer use.

In realizing these objectives neoclassical household production and consumption models, neoclassical expected and non-expected (prospect theory) models, and neoclassical intertemporal choice models are formulated and estimated to analyze the economic decisions of farmers under risk. Models are estimated using a four-year panel data of Tigray rural farm households.

1.4 Thesis outline

The objectives of the research, which are stated in section 1.3, are elaborated and analyzed in greater detail in this thesis. In chapter 2 the data set is introduced. The data was collected in Tigray, Northern Ethiopia. The first data set was collected for 1996 and 1997. The information was not updated until 2001 for the same group of farmers; nevertheless, the panel structure of the data provides a unique opportunity in studying risk behavior of farmers. This chapter helps to acquaint readers with the study areas' farming systems, households' ownership of productive assets, and household characteristics. It describes the various sources of household incomes and rainfall patterns in the study areas.

In chapter 3 a review of the literature on expected utility and non-expected utility is provided. Theories which are commonly used to explain decision-making under risk are reviewed and evaluated. Much attention will be devoted to the expected utility model and measurement of attitudes toward risk. Some criticism of the descriptive inaccuracy of the expected utility model is presented and alternative descriptive models like prospect theory are discussed.

In chapter 4, methods and procedures for assessing farmers risk attitudes are presented. The main objective of this chapter is to determine whether household's risk aversion behavior is consistent with the conventional expected utility theory or with prospect (non-expected utility) theory. Furthermore, the relationship between farmers' risk attitudes and their household characteristics is analyzed.

In less-favored areas like Tigray crop production is risky and opportunities are limited for insuring ex-post risk through markets and many farm families depend directly on crop diversity as a risk coping strategy ex-ante. Hence, chapter 5 will examine the effect of rainfall risk and households' socio-economic conditions on crop choice. Here crop choice is modeled as a binary model. To estimate the land allocation model the seemingly unrelated regression estimation method has been used.

As described in the introductory part labor is the principal asset owned by the poor. Chapter 6 analyzes farm household's off-farm labor supply response to different rainfall conditions. An off-farm labor supply function is derived from a household model that incorporates rainfall and rainfall risk. A Hausman-Taylor panel data estimator is used for estimation. It further estimates the extent to which labor supply increases/decreases with variability in rainfall, and what other mechanisms households use to mitigate risk.

Moreover, missing credit and insurance markets imply that households have to use different strategies to smooth consumption ex-post. Chapter 7 will analyze the effect of ex-ante risky input adoption (fertilizer) on ex-post consumption. Here an intertemporal choice model was used.

Finally, Chapter 8 is a synthesis of preceding chapters and presents it in such a way that it addresses the research questions and its implications for development policy and further research is suggested.

Chapter 2
Description of the Region Studied and Data

2.1 Introduction

With a per capita GDP of 100 USD in 1999/00 (MOFED, 2002) Ethiopia ranks among the poorest countries in the world. The agricultural sector, mainly of a subsistence nature, counted for 45 percent of national income, and 90 percent of foreign exchange earnings and it absorbed 85 percent of the total labor force in 2005 (World Bank, 2005). Located in the semi-arid tropics of Sub-Saharan Africa with a population of over 70 million in 2003 and increases by 2.9 percent per annum, the country suffers of high rainfall variability and frequent harvest deficits (World Bank, 2004). GDP grew at an annual average rate of close to 5% during 1992/93-2000/01, with sectoral growth rates of 2.5 percent for agriculture. Within agriculture the crop sub-sector registered an annual average growth rate of 4.9% during 1992/93-2000/01 (MOFED, 2002). The average annual increase of the crop sub-sector is mainly attributed to good rains and to the adoption of fertilizer and high yielding varieties.

Like many other African countries Ethiopia already underwent, in 1992, a structural adjustment program, with 143 percent devaluation of its local currency, the Birr, in order to promote their exports and control their balance of payments.[5] Nevertheless, Ethiopia still experiences balance of payments deficits due primarily to a swollen public sector, the country's high dependence on imports, and the absence of strong comparative advantages. By effect, poverty and high external debts do not enable the country to secure the basic needs of a rapidly growing population and to invest in sustainable poverty reducing development programs. Ethiopia encounters significant food insecurity, e.g. the proportion of the population below the poverty line was 44 per cent in 1999/2000. Thus, food security was and is central on the development agenda of the government (World Bank, 2005; MOFED, 2002).

Improving agricultural productivity is therefore, recognized as a major policy and research issue in addressing declining trends in per capita food production in the country. This has generated considerable policy debate about alternative technical and policy interventions that may improve food security in Ethiopia (MOFED, 2002). To enhance the welfare of the predominantly rural population, land productivity has to improve. In effect, various government policies have targeted the efficient use of rural resources, especially land and labor.

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[5] Devaluation is defined as the lowering of the official value of a local currency against other currencies, so that exports become cheaper and imports more expensive. Used when a country is badly in deficit in its balance of trade, it results in the goods the country produces being cheaper abroad, so that the economy is stimulated by increased foreign demand (Blanchard and Fischer, 1989).

The objective of this chapter is to: (i) briefly report on the socio-economic conditions of the households in the study areas; and (ii) provide some understanding of the farming systems, income composition, credit and land markets.

Section 2.2 provides a description of the region studied, data description is presented in section 2.3, and section 2.4 presents discussion and conclusions.

2.2 Region Studied

Tigray is located in the most northern part of the country. It belongs to the Sudano-Sahelian agro-climatic region of Ethiopia. Its climate is characterized by one long dry season from October to May, followed by a short rain season from March to April and the long rain season from June to late September. Tigray region receives rainfall between 550 and 650 mm annually. The districts studied are called Enderta and Hintalo-Wajerat[6] and occupy the southern part of the region. Enderta is said to be a good rain-fed agricultural area, and Hintalo-Wajerat a drought prone area, where severe crop deficits occur. The economies in both districts are characterized by transition from a pure subsistence to a semi market economy. Enderta is close to Mekelle the capital city of Tigray where there are many opportunities for off-farm work. Hintalo-Wajerat is located further away from Mekelle and farmers have less opportunity for off-farm work (particularly for wage employment work). More than elsewhere, food insecurity is particularly acute in the Hintalo-Wajerat district due to high rainfall variability and poor soil moisture retention.

The study areas, Hintalo-Wajerat and Enderta, receive an annual rainfall of 400 mm and 600 mm respectively. The traditional production system of low-input mixed farming, described as a drought spatial adaptive mechanism, is common in both districts. Most households use traditional production techniques. Traditional techniques of farm production include wooden plows, ox-plowing, and hand sickles. The primary objective of households is to satisfy subsistence food requirements. The cropping system is mainly based on cereals: teff[7], wheat, and barley producing the staple diet. Lentil and grass pea are the most commonly grown pulses in the study areas. Livestock is an indispensable component in the subsistence economy in the study areas. A farm household is used to have one or a pair of oxen for draft power and a donkey used for transport of crops from fields to home and to the marketing centers. Livestock represents the predominant form of household wealth along with the type of materials from which the house is

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[6] The Hintalo-Wajerat district was formerly called Adigudom district.
[7] Teff is a cereal unique to the highlands of Ethiopia and is a cash crop.

constructed. Livestock is also needed as a means of supplementing crop production and as a source of income to purchase grains over the dry season. In these areas, social status is directly correlated to livestock size and the type of house and household materials. Deficit years are usually caused either by a lack of rainfall or by an uneven distribution of rainfall throughout the production season. In general, reported famines and periods of food shortfalls correspond to years when annual rainfall was below average.

There are two means of acquiring land; either the land is allocated to the farm household by the peasant association (local administration) or the farm household rents land. Land rent is paid either in the form of sharecropping or fixed rent. Households draw most of the labor they require from household members. However the seasonal nature of some of the activities makes household labor periodically insufficient. Labor shortage particularly occurs during the weeding and harvesting seasons. To meet the high labor demand during different agricultural operations, farm households depend on labor-sharing arrangements and on hired labor. Moreover, variations in the demand for labor, especially for crop production activities, necessitate scheduling farming operations to suit family labor availability. This is especially true for those households that are not able to hire external labor.

Most of the households belong to the Coptic Orthodox Church (98.5%) and generally work an average of 15 days per month during the cropping calendar due to restrictions imposed by the religious calendar.

2.3 Data Description

The data for this thesis come from a four year (1996, 1997, 2001, and 2002) household survey in the two study areas. Among other information, the data include household crop production and input use, livestock ownership, household labor allocation and household head risk assessment data.

The two study areas were chosen because of the substantial differences in rainfall patterns and variations in access to markets.[8] All the necessary information such as household composition, allocation of labor, credit, crop production, and livestock inventory data were recorded during interviews with the head of the household once a year.

Almost all (99 percent) households that were in the sample in 1996 and 1997 were still in the 2002 survey. This is an important feature of the data set. One of the farm households dropped out because of moving to another place and one household was not recognizable by the villagers.

[8] For details on the selection criteria of the study area see Woldehanna, 2000.

The interview was conducted by a house to house visit. When the head of the household passed away the land and other assets were passed on to the widowed or to a daughter/son. This permitted to construct a panel of households over the four year period.

For comparison purposes and to get more insight in the nature of the dataset, the sample households were stratified based on the number of oxen. Oxen are generally accepted indicators of wealth in the study areas, as oxen are crucial in ox-plough farming systems.[9] The number of observations in each wealth category is provided in Table 2.1.

Table 2.1 Number of observation in each wealth category

	Wealth classification	Number of observations
No oxen	Very poor	148
Only one oxen	Poor	203
Two oxen	Less poor	341
>two oxen	Better-off	104
Total Observations		796

Demographic characteristics

From Table 2.2 it becomes clear that literacy rate is strongly related with wealth. For the better-off farmers the literacy rate for the head was about 48 percent while for the very poor it was only 20%. Moreover Table 2.2 also provides evidence on the relationship between female headship and poverty. It might be the case that poor female headed households may be more vulnerable to income fluctuations, since they have limited access to productive resources such as oxen. Almost 49% of the very poor households were headed by women. For the better-off households only 8% of the families are female headed (see Table 2.2).

Table 2.2 Descriptive Statistic of household characteristics (mean and standard deviations (SD))

	Very poor		Poor		Less poor		Better-off	
Variables	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age of head	49.67	13.79	48.84	11.04	49.31	11.72	53.37	11.67
Head is female (%)	48.65		7.88		4.4		5.77	
Family size	4.13	2.26	5.82	2.08	6.16	1.88	6.74	1.97
Number of adults above 15 year	2.13	1.06	2.70	1.00	2.80	0.96	3.38	1.38
Children <15 years	1.99	1.66	3.08	1.83	3.33	1.70	3.33	1.60
% head illiterate	80.41		65.52		62.17		51.92	
% members that can write and read	57.43		73.89		74.78		80.77	
Number of dependents	1.98	1.73	3.17	1.83	3.43	1.69	3.56	1.68
Dependency ratio[10]	1.05	0.94	1.38	0.92	1.47	0.88	1.26	0.78

[9] The regional government also uses this wealth classification in order to provide food aid for the most needy farm households.

Family size and dependency ratio increase with wealth status of the household. For the very poor the average family size and dependency ratio are 1.05 and 4.13 respectively, while for the better-off households they are 1.26 and 6.74 respectively.

Income composition

Most of the households do not restrict themselves to a single activity but receive incomes from various sources. Their multiple sources of income are cropping activities, wage employment, self-employment, and non-labor income. Crop income is income received from farming activities (production of crops). Crop income is usually received one or two times during the year. Wage employment and self-employment income are incomes earned from off-farm activities. Wage employment income comprises income received from working for paid development work (such as food for work), regular jobs (such as masonry, and carpentry), and casual daily work. Self-employment income comprises income earned from selling fire wood and homemade charcoal, stone mining, hiring out of animals (such as transport animals, like donkeys, horses and camels), grain and livestock trading, petty trading (selling of cactus fruits), and handcraft. Wage and self-employment incomes can be spread over the year to reduce overall income variability (for details on income diversification and composition in the study areas see Woldehanna and Oskam, 2001; Woldehanna, 2000). Finally non-labor income includes income received from relatives, gifts, inheritances and government food aids. Descriptive statistics of income composition for the different household categories are presented in Table 2.3.

Table 2.3 Descriptive statistic of average income composition by households (mean income in Birr and standard deviations in parentheses)[11]

	Very poor		Poor		Less poor		Better-off	
	Mean	% share	Mean	% Share	Mean	% Share	Mean	% Share
Crops	697.95	36	1532.33	54	2026.77	62	3816.98	75
	(533.74)		(874.69)		(1318.66)		(2923.48)	
Wage	774.51	40	684.41	24	541.90	16	310.15	6
	(1168.00)		(1066.03)		(1028.48)		(1045.58)	
Self-employed	196.88	10	327.42	12	424.47	13	689.73	13
	(453.51)		(759.73)		(1262.62)		(1439.58)	
Non-labor[12]	280.24	14	293.61	10	288.11	9	302.73	6
	(709.43)		(867.23)		(1135.27)		(937.82)	

[10] Dependency ratio is defined as the number of children below 15 years of age plus elderly above 65 years divided by the number of adults (15-65 years).

[11] All incomes are expressed in the Ethiopian currency Birr (the official exchange rate per US dollar was: 8.57 (2002), 8.46 (2001), 6.71 (1997), 6.35 (1996) (World Bank, 1999; World Bank 2005). The data gives gross incomes, before deducting cash expenditure on agricultural and non-agricultural inputs. Crop income also includes land rental income, mainly from sharecropping and cash rents.

[12] The share of non-labor income decreases with the number of oxen owned by households.

Table 2.3 shows that crop income is an important source of income for better-off households while the poor households generally rely on wage incomes. For the poor households only 35% and 40% of their income is derived from cropping activities and wage income respectively. For the better-off households, cropping activities and wage income form 75% and 6% of their income respectively. We used a t-test for crop income sample mean comparison between the poor and better-off households. The t-value of 6.00 is significantly different from zero at the 5% critical value, thus it can be concluded that there is a difference in mean of crop incomes between poor and better-off households. This indicates that crop income is likely to be affected by the availability of oxen and labor.

Self-employment income increases with the wealth status of the household. For the better-off households the share of self-employment income is 13% and for the very poor households it is 10%. About 33% of the poor (sum of the very poor, poor and less poor) engage in selling fire wood and homemade charcoal, while only 4% of the better-off households are engaged in such activity (see Table 2.4). Most of the better-off households were engaged in stone mining, grain and livestock trading, and renting out of transport animals. These activities involve some entry barriers, usually in the form of basic investments for buying animals and equipments. However, little investment and skill is needed for collecting and selling firewood and homemade charcoal.

Table 2.4 Percentage of households engaging in self-employment activities

Type of self-employment	Very poor	Poor	Less poor	Better-off
Stone mining	2.03	4.43	4.40	4.81
House rent	0	0.49	0.59	5.77
Hand crafts	6.08	2.46	0.88	0
Grain and livestock trading	2.03	4.93	9.97	13.46
Rent transport animals	2.03	6.89	5.57	16.34
Selling firewood and charcoal	7.44	13.30	12.41	3.85
Others (such as selling cactus)	7.43	3.94	8.80	1.92

Crop choice

Depending on the amount and intensity of rainfall farmers grow a variety of crops. Teff, wheat, barley, grass pea, and lentil are the dominant crops grown in the two study areas. These crops have different levels of susceptibility to moisture stress, input requirements and storage for home consumption and the potential for cash income. Barley was the first choice by very poor, poor and less poor households. Barley is the second choice for the better-off households (see Table 2.5).

Table 2.5 Crop choice by households (in percents)

Crop type	Very poor	Poor	Less poor	Better-off
Barley	76.54	86.57	90.59	92.23
Wheat	64.06	74.63	84.41	93.20
Teff	54.69	72.14	76.18	81.55
Grass pea	12.50	29.85	35.00	49.51
Lentil	4.69	8.46	14.41	21.36
Number of observations	64	201	340	103

Wheat is the second choice for all wealth categories except for the better-off, where it is the first choice. Teff is mainly produced for the market and is considered to be a cash crop. Teff was chosen by 55% and 82% of the very poor and better-off households respectively.

Grass pea, a legume, was chosen by 13% and 50% of very poor and better-off farmers respectively. The entire plant is also used as animal feed. Lentil - a legume crop - was chosen by 5% and 21% of very poor and better-off farmers respectively. Most of the time lentil was chosen for marketing purposes.

Variable input use

Although credit has been available through credit and saving institutions for purchase of inputs particularly fertilizer, use of fertilizer was low for the very poor (28%) when compared to the better-off farmers (76%).The t-test of sample mean equality between the utilization of fertilizer between the poor and better-off households is significant at the 5% critical level. This indicates that the poor are more risk-averse than the better-off farmers. This is consistent with the general belief that the poor take up low-risk activities at the cost of low returns.[13] This is partly explained by the uncertain and erratic rainfall conditions which do not motivate farmers to buy fertilizer. In addition due to low cereal prices in good rainfall years farmers had difficulties to repay their loans. That weakened their financial capacity and generated a loss in confidence to continue buying fertilizer.

Table 2.6 Variable input use by households (in percents)

	Very poor	Poor	Less poor	Better-off
Commercial fertilizer	28.13	45.27	53.53	75.73
Improved seed	6.25	15.42	15.29	27.18
Pesticide	1.49	2.94	3.13	4.85
Herbicide	0	0.50	2.91	3.24
Number of observations	64	201	340	103

Pesticide and herbicide use was very limited by all households. This is because pest management in smallholder agriculture heavily relies on the production techniques used. Farm

[13] To smooth income households use less risky, traditional, production techniques at the expense of low returns (Morduch, 1995: 104).

households use traditional production techniques including mixed cropping, timely planting, intercropping, crop rotation as local and traditional pest control methods.

Production and input use by crop type

Differences in input requirement by crop are noticeable, particularly with respect to labor, land, and commercial fertilizer (see Table 2.7). Most labor is devoted to teff, because teff is a labor demanding crop. The land has to be plowed more than three times and weeded more than twice (Woldehanna, 2000: 158).

Table 2.7 Yield and input use per hectare (standard deviations in parentheses)[14]

	Barley	Wheat	Teff	Grass pea	Lentil
Share of land (ha)	0.39	0.35	0.30	0.22	0.18
	(0.19)	(0.16)	(0.17)	(0.13)	(0.08)
Commercial fertilizer (kg)	26.28	29.03	17.39	0	0
	(52.59)	(50.51)	(42.80)		
Improved seed (kg)	1.08	17.79	1.00	0	0
	(17.37)	(47.75)	(10.17)		
Local seed (kg)	160.56	121.26	49.32	24.29	27.36
	(58.83)	(61.36)	(29.05)	(11.88)	(19.31)
Labor (hours)	325.56	355.16	724.79	281.18	302.02
	(166.92)	(202.91)	(469.50)	(151.09)	(249.77)
Yield (Kg)	744.47	576.26	506. 67	510.74	329.20
	(421.79)	(327.55)	(342.95)	(315.40)	(340.22)
Number of observations	627	575	524	238	91

On average 39% of cultivated land was devoted to barley. As discussed before, barley is the main staple food crop in the study areas and farmers aim to produce enough food to feed the family. Only surpluses are sold. Commercial fertilizer and improved seed use are highest for wheat (see also Woldehanna, 2000).

Credit

Credit is provided by local credit and saving institutions called Dedebit Credit and Saving. Their target beneficiaries are poor households. Due to lack of collateral held by rural households and as to guarantee loan repayments a group consisting of 8 people is eligible for borrowing. In doing so, the group vouches for the beneficiaries of the loans, and thus becomes responsible for collecting loan repayments from the member farmers. Most of the borrowing has been for purchasing of agricultural inputs such as fertilizer and improved seed and farm oxen. The poor (57%) and the less poor (54%) are most dependent on credit. The very poor used more than 6% of

[14] Sample mean is calculated for positive values (either zero allocation of land to crops or zero labor input are excluded)

the total loan for consumption purposes.[15] The better-off farmers used most of the credit for purchase of oxen and agricultural inputs.

Table 2.8 Percentage of farm households using credit and reasons for lending

	Very poor	Poor	Less poor	Better-off
Percent of credit beneficiaries	34.46	57.14	54.25	41.35
Reasons for loan:				
To buy farm oxen and other animals	17.57	29.55	24.34	18.27
To buy agricultural inputs	7.44	16.75	20.52	20.19
To buy food	6.76	5.42	3.81	2.88
To start small and micro business	2.03	2.96	4.69	0
Others (to pay tax and loans)	0.68	1.97	0.88	0
Number of observations	148	203	341	104

Land

All the households in the sample use agricultural land. The tenure system prohibits private ownership and sale of land, but allows for temporary land transfers by lease. About 11 percent of the households did not cultivate their land (i.e., they rent it out). The average land cultivated by the better-off household was 3.28 hectares. On average only 0.45 hectare of land was cultivated by the very poor households, as these households lack oxen they rely heavily on renting out of land. 72% of the very poor household rent out their land using a sharecropping contract.[16] Table 2.9 shows that area of cultivated land increases with number of oxen (as wealth categories are determined on the basis of the number of oxen).

Table 2.9 Percent of households participating in renting in and renting out of land

	Very poor	Poor	Less poor	Better-off
Mean cultivated land in hectare (standard deviation in parenthesis)	0.45 (0.65)	1.52 (0.63)	2.07 (0.83)	3.28 (1.71)
% rent in	5.41	28.57	60.41	75.00
% rent out	72.30	14.78	4.11	4.81
% rent in and rent out	76.35	40.39	63.93	78.85

The better-off farm households rely heavily on rented land in their farming operations (see Table 2.9). Most contracts are between households living in the same community where everybody knows and can monitor each other well.

[15] Credit is available for productive purposes only. However, it is not uncommon to use loans for other purposes. The very poor more often use credit for consumption purposes rather than for purchasing agricultural inputs or for starting a small business. They use credit as consumption smoothing mechanism.

[16] Cropland is typically rented in one of three ways: (i) crop share; (ii) cash rent; (iii) cash/share combination. More than half of the farm households who rent out their land use crop share contracts. In the presence of production risk and missing insurance markets, households can use crop share contracts as a risk sharing mechanism.

Rainfall

Agricultural production in the study areas heavily depends on rainfall. For all farm households, rainfall is the major source of moisture for crop and livestock production. However, large rainfall variability is a common phenomenon in the study areas. Over the ten year period average rainfall was higher for Enderta than for Hintalo-Wajerat. Enderta received a 10 year average rainfall of 554.95 mm, with a standard deviation of 101.18 mm and a coefficient of variation[17] 18%. Similarly, Hintalo-Wajerat received a 10 year average rainfall of 541.67 mm, with a standard deviation of 228.70 mm and a coefficient of variation of 42% (see Table 2.10). As can be confirmed from the descriptive statistics Hintalo-Wajerat is a drought prone area. The high coefficient of variation for Hintalo-Wajerat shows the high degree of rainfall variability.[18] A minimum rainfall of 409.20 mm and a maximum of 729.60 mm were recorded for Enderta, while a minimum rainfall of 277.70 mm and a maximum of 1103.50 mm were recorded in Hintalo-Wajerat (for details see Appendix 2.I). The year to year variation is a clear indication of the existence of rainfall-induced risk in the study areas.

Table 2.10 Descriptive statistic of rainfall (mm) for the 10 year period (1993-2002)

District	Observations	Mean	Standard Deviation	Min	Max	Coefficient of Variation
Enderta	10	554.95	101.18	409.20	729.60	0.18
Hintal Wajerat	10	541.67	228.70	277.70	1103.50	0.42

2.4 Discussion and Conclusions

In this chapter, we described the socio-economic characteristics of farm households in the districts Hintalo-Wajerat and Enderta in Tigray covering the years 1996, 1997, 2001, and 2002. We discussed income composition, crop choice, input use, credit, and land markets. The data was disaggregated based on the number of oxen owned by households. Rainfall data of the period 1993 to 2002 years were used to describe the seasonality and variability of rainfall in the study areas.

High seasonality (intra-annual) and high variability (inter-annual) of rainfall are common characteristics of the districts studied. The coefficient of variation of rainfall is 42% and 18% in Hintalo-Wajerat and Enderta respectively.

[17] Coefficient of variation is defined as the standard deviation divided by the mean.

[18] Dercon (2002: 2) also gives details on the various shocks and events causing serious hardship to rural households in Ethiopia during the last twenty years. He showed that about 78% of households reported to be having been severely affected in harvest failure caused by rainfall variability.

Households diversify their income sources and thus minimize the effects of negative rainfall shocks. Rural households in the survey districts generate income from crop, off-farm wages, off-farm self-employment, and non-labor income for their livelihoods.[19] The degree of dependence on these activities varies according to the socio-economic status of the households. Better-off households with more than two oxen, for example, were less reliant on off-farm wage employment and non-labor income (such as food aid) than those who were considered poorer (i.e., with one or no oxen).

In the study areas, households rely on crop diversification. Crop diversification is a means to reduce the risk of crop failure, which is caused by rainfall risk. Farm households also implement conservative agricultural production strategies. Farmers' chose to plant traditional varieties, which they know and understand the water requirements. For example improved seed and fertilizer use in the study areas was low, with an average of 6.62 kg of improved seed per hectare and 24.23 kg of fertilizer per hectare were applied.[20]

Fertilizer use increases with the number of oxen (wealth) owned by the household. Only 28% of the very poor households were using fertilizer in the study period. Further, the poor enter into activities and asset portfolios with low risk, but also low returns, this in turn affects their long-term income. The better-off households invest into profitable but more risky activities (use of purchased inputs and trading).

The descriptive analysis showed that, to minimize the risk of crop loss and in an attempt to adjust the area cultivated to factor endowments (i.e. number of oxen and labor), about 72% of the poor enter into land rental markets.

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[19] The importance of income source diversification as part of risk management is emphasized by Dercon, (2002: 143), stating that households with more volatile farm income are more likely to diversify their income sources.

[20] Brouwer and Bouma (1997) concluded that one reason for such low fertilizer use is that farmers avoid investing in inputs due to high risks of crop failure as a result of rainfall variability.

Appendix 2.I Rainfall Patterns

Precipitation data of total monthly rainfall in the period 1993-2002 were obtained from the database of the Ethiopian National Meteorological Service Agency. Rainfall was measured daily with a rain gauge at each site. The daily amount of rainfall was summed to yield monthly rainfall. The monthly amount of rainfall was summed to yield annual rainfall for each year (see Table 2.I).

Table 2.I Annual precipitation in the two study areas[21]

Year	Enderta	Hintalo-Wajerat
1993	610.1	412.6
1994	614.7	639.2
1995	581.6	558.7
1996	515.9	426.9
1997	462.6	364.6
1998	648.5	1103.5
1999	729.6	553.9
2000	436.3	455.4
2001	541.0	624.2
2002	409.2	277.7

Minimum rainfall amounts of 409.20 mm and 277.70 mm were recorded in the year 2002 in Enderta and Hintalo-Wajerat respectively.[22] Rainfall amounts were the highest in 1998 and 1999 in Hintalo-Wajerat and Enderta respectively. It should be noted that the minimum and maximum rainfall amounts represent annual rainfall amounts summed over the months. To say more about rainfall variations over years we computed annual rainfall deviations from the 10 year average (in percentages). The annual rainfall deviations are given in figure 2.I.

Figure 2.I Annual Rainfall Deviation from the 10-year Rainfall Average

It is clear that the deviation of annual rainfall from its 10-year average was very high in the year 2002, with deviations reaching up to -146% and -264% in Enderta and Hintalo-Wajerat

[21] All rainfall measures are in millimetres.
[22] This is consistent with the national figures which suggested 2002 was quite a bad year, which threatened about 13 million people with famine (MOFED, 2003).

respectively. Similarly, negative deviations from the 10-year period were also observed in the year 1996 and 1997. The negative rainfall deviation in 1996 and 1997 were succeeded by positive rainfall deviations in the year 1998 in both of the districts, with values of 12% and 175% higher than the 10-year average rainfall in Enderta and Hintalo-Wajerat respectively.[23] The occurrence of such high discrepancy between the positive and negative deviations within the 10-year period implies the existence of rainfall-induced risks in the study areas.

[23] Similarly, at country level there was catastrophic flooding in 1998 that compounded the shortage of food (Wolde-Georgis *et al*., 2001).

Chapter 3
Expected Utility versus Non-Expected Utility: Literature Overview

3.1 Introduction

Agricultural production is characterized by risk. Dependence of production on biological processes makes it susceptible to uncertain climatic behavior and to pests and diseases. This leads not only to uncertainty in the level of production, but also to uncertainty in output prices. This can result in severe income losses and to fluctuations in consumption. Given their limited ability to offset these shocks, many rural households suffer from extreme farm income fluctuations. The prevalence of rainfall-induced risk is not new and farmers have developed ways of reducing and coping with risk (e.g. crop diversification, storage and asset accumulation). Although the virtues of these risk management mechanisms are widely recognized, they also have their limitations. They can be costly in terms of the income opportunities that rural household forego (e.g. crop diversification is typically less profitable than specialization). They might discourage investments and technological changes that, while risky, enhance long-term agriculture productivity growth. Farmers have limited capacity to spread covariate risks like droughts that affect almost all households in a region at the same time. In theory, these limitations would not exist if capital and insurance markets were perfect and could pool risks more widely, but the reality for many developing countries is quite the opposite, relevant capital and insurance markets are poorly developed and they are weakly linked across regions and with urban areas (Hazell, 1982). As a result farm households' economic decisions are highly influenced by the absence of credit and insurance markets (Binswanger, 1980, 1981, 1982; Antle, 1983, 1987).

Modeling of decision making under risk centers on the classical expected utility model of individual choice under risk and the non-expected utility model, which assumes that individuals do not maximize expected utility. The main objective of this chapter is, therefore, to give an overview of the expected utility model - and its caveats - and of prospect theory as one of the possible alternatives for the expected utility model of individual decision making under risk.[24]

The rest of the chapter is organized as follows: the following section presents a review of expected utility theory and its implication for decision making under risk. Section 3.3 presents some violations of expected utility theory. Section 3.4 reviews one of the models generalizing expected utility theory, prospect theory. Section 3.5 presents a discussion and conclusions.

[24] For the definition of risk and uncertainty see footnote 1 of this thesis. For a discussion on modelling choice under uncertainty, see Savage (1954).

3.2 The expected utility theory

Background

In general the expected utility (EU) model has been the dominant model for the last decades in modeling behavior under risk. Von Neumann and Morgenstern (vNM) are the major contributors to a large body of work that provides the justification for the use of the expected utility model by a rational decision maker. This model views decision making under risk as a choice between alternatives. Decision makers are assumed to have a preference ordering defined over the probability distributions for which the axioms of the EU model hold (Mas-Colell *et al.*, 1995). Risky alternatives can be evaluated under these assumptions using the expected utility function $U(x)$.

In maximizing the decision maker's utility, consider a risk prospect in which the decision maker does not know ex-ante which state of the world will occur. However he can list the various alternatives and can attach probabilities to them. For simplicity, assume two possible states of the world, state 1 and state 2, with respective probabilities p1 and p2 and denote x_1 the individual's monetary gain if state 1 occurs and x_2 if state 2 occurs. The individual must choose ex-ante between the risky bundles (x_1, x_2). Ex-post, the individual gets x_1 or x_2 depending upon which state of the world has occurred. If the decision maker's preference ordering over risky alternatives satisfies all the axioms of expected utility, including the independence and continuity axioms (see next section), then there exists a vNM expected utility function. This vNM expected utility function reflects the decision maker's choice as if he maximizes utility of the different states weighted by the probabilities for each state to occur.

vNM began by stating that utility maximization is a rational goal when a decision maker is faced with risky choices. In this framework, an individual will evaluate the expected value and objectively given probability of occurrence of each alternative. This evaluation is carried out by first entering the probabilities and expected outcomes into an individual's utility function. It is then a matter of selecting the combination of available alternatives that maximizes the function. The manner in which individuals choose among available alternatives is then dependent upon their utility function. For this setting the vNM expected utility function can be specified as:

$$U(p_1,..,p_i,..,p_N) = \sum_{i=1}^{N} p_i u(x_i) \qquad (1)$$

where U is the vNM expected utility function, $u(x_i)$ is the utility of the ith element of a vector of possible outcomes, and p_i is the probability of outcome x_i, $\sum p_i = 1$. The vNM expected utility function $U(p_1,..., p_i,..., p_n)$, defined up to a positive linear transformation, characterizes both the utility of the outcome and the individual's attitude toward risk. The curvature of this utility function contains information about the degree of individual's risk aversion (Mas-Colell *et al.*, 1995: 173).

Axioms of the expected utility theory

There are three main axioms in the expected utility framework. They are defined over a binary relation where:

$\succeq$ denotes weak preference,

$\succ$ denotes strict preference, and

$\sim$ denotes indifference.

For preferences over probability distributions $p, q, r \in P$ that are defined over a common (discrete or continuous) outcome vector X. The three axioms that are necessary and sufficient for the expected utility representation $U(\cdot)$ over preferences are:

Axiom O (Order):

The binary relation $\succ$ on P is asymmetric and transitive. The asymmetric part of axiom O says that the decision maker will not both prefer p to q and prefer q to p. According to expected utility theory, it is irrational to hold a definite preference for p over q and a definite preference for q over p at a time. However, there is a possibility that neither p nor q is preferred (i.e. $p \sim q$, the decision maker is indifferent between p and q).

The transitivity part of axiom O holds if and only if both $\succ$ and $\sim$ are transitive, i.e., for all $p, q, r \in P$, ($p \succeq q$, and $q \succeq r$) $\Rightarrow p \succeq r$; ($p \sim q$ and $q \sim r$) $\Rightarrow p \sim r$. Transitivity implies that it is impossible to face the decision maker with a sequence of pair wise choices in which preferences appear to cycle. For example, a decision maker feels that an apple is at least as good as a banana and that a banana is at least as good as an orange but then also preferring an orange over an apple.

Axiom C (Continuity):

For all $p,q,r \in P$ with $p \succeq q$ and $q \succeq r$ there exists $\alpha, \beta \in (0,1)$ such that: $\alpha p + (1-\alpha)r \succeq q$ and $q \succeq \beta p + (1-\beta)r$. This axiom gives continuity to the preferences. Continuity means that small changes in probabilities do not change the nature of the ordering between two lotteries (see Mas-Colell *et al*., 1995: 171). Continuity rules out lexicographic preferences.

Axiom I (Independence):

For all $p,q,r \in P$ and for all $\alpha \in (0,1)$, if $p \succeq q$, then $\alpha p + (1-\alpha)r \succeq \alpha q + (1-\alpha)r$. This axiom states that preferences over probability distributions should only depend on the portions of the distributions that differ (p and q), not on their common elements (r) and of the level of α that defines the linear combination. In other words, if we mix each of two lotteries with a third one, then the preference ordering of the two resulting mixtures does not depend on the particular third lottery used.

Axioms O, C, and I can be shown to be necessary and sufficient for the existence of a function $U(\cdot)$ on the outcomes $x \in X$ that represents preferences through $\succeq$. The role of the order, completeness and continuity axioms are essential to establish the existence of a continuous preference function over probability distributions. It is the independence axiom which gives the theory its empirical content and power in determining rational behavior. That is, the preference function is constrained to be a linear function over the set of probability distribution functions, i.e. linear in probabilities (Machina, 1982: 278).

Theoretical Measures of Risk Attitude

A theoretical measure of risk aversion was independently proposed by Pratt (1964) and Arrow (1970) based on the vNM utility function. Two measures have resulted. One is a measure of absolute risk aversion:

$$r_A(x) = -\frac{u''(x)}{u'(x)} \tag{2}$$

The other is a measure of relative risk aversion:

$$r_R(x) = -x\frac{u''(x)}{u'(x)} \tag{3}$$

where $u(x)$ is a vNM expected utility function with properties $u' > 0$ and $u'' < 0$, u' and u'' indicate the first and second order derivative of the expected utility function and x is the wealth or income position.

The indexes are positive, zero, or negative for risk-averse, risk neutral, and risk taking decision makers, respectively. Both Pratt (1964) and Arrow (1970) hypothesized that a risk-averse decision maker would display decreasing (non-increasing) absolute risk aversion for increases in x. A risk-averse individual with decreasing relative risk aversion will exhibit decreasing absolute risk aversion, but the converse not necessarily holds (Mas-Colell *et al*., 1995: 194).

Following the work of Pratt (1964) and Arrow (1970), Menezes and Hanson (1970) proposed a related measure of risk aversion referred to as partial relative risk aversion. It is defined as

$$P(x,t) = -t\frac{u''(x+t)}{u'(x+t)} \tag{4}$$

where $u(x)$ and x are as defined above and t is income associated with a new prospect that is increasingly risky for increases in its payoff. Both Menezes and Hanson (1970) hypothesized that a risk-averse decision-maker would display increasing (non-decreasing) partial relative risk aversion for increases in the prospect t.

To conclude, the expected utility model is based on axioms explaining individual behavior. The axioms are assumptions in choosing risk alternatives and describe how a rational individual should behave. If an individual obeys the expected utility axioms, then a utility function can be formulated that reflects the individual preferences (Mas-Colell *et al*., 1995: 175; Robison and *et al*., 1984: 13). Further individual's risk attitude can be inferred from the shape of his/her utility function. To this end, the predictive power of expected utility theory is tested through experiments or inferences made from actual observed economic behavior. Since vNM (1947), the expected utility model has been the dominant model in predicting choice behavior under risk. Starting with the well-known paradox of Allais (1953), however, a large body of experimental evidence has been documented which indicates that individuals tend to violate the axioms underlying the expected utility model systematically. This empirical evidence has motivated researchers to develop alternative theories of choice under risk able to accommodate the observed patterns of behavior. A wave of theories designed to explain the violation of expected utility theory began to emerge at the end of the 1970. Examples are prospect theory (Kahneman and Tversky, 1979), regret theory (Loomes and Sugden, 1982), dual theory (Yaari, 1987), cumulative prospect theory (Tversky and Kahneman, 1992), and rank-dependent utility (Quiggin, 1993). For a thorough review see Starmer (2000). In the empirical literature prospect theory is the dominant theory. Therefore, it will be discussed in section 3.4.

3.3 Violation of Expected Utility

There have been many advances in the economic analysis of decisions under risk using the expected utility model (e.g., Sandmo, 1971; Newbery and Stiglitz, 1981; Antle, 1987). These all take the validity of the expected utility model as given. However, a serious challenge to the use of expected utility was made as early as 1950s to show that expected utility lacked complete predictive and hence descriptive validity. Experimental investigations revealed a variety of inconsistencies between observed choice behavior and expected utility. Roughly speaking, expected utility violations are of two kinds: those which can be explained by some generalizations of expected utility, and those which challenge the very existence of well-defined preferences. The following subsections report some of these violations.

3.3.1 Violation of the independence axiom

The independence axiom has been the most extensively investigated axiom from an empirical perspective. Allais (1953) opened the way and reported experimental evidence showing systematic violations of independence. These violations are the so-called common consequence effect and common ratio effect. They say that outcomes are not independent and agents show a higher degree of risk aversion for losses than for gains. Therefore, the independence axiom does not hold and we would expect the expected utility model to be violated. Most examples of the common consequence effect and common ratio effect have involved choices between pairs of prospects.

The common consequence effect. The well-known risky choice provided by Allais is given in a paper by Kahneman and Tversky (1979). They synthesize the work by Allais and by others who have shown experimental violations of expected utility. The Allais paradox depicted in Table 3.1 is the leading example of this class of anomalies. There are two different choice sets, for each choice set there are two lotteries from which you can choose. For example, in lottery A1 there is a guaranteed payoff of $1M and there is zero probability of winning nothing. In lottery

A2 there is a 0.10 probability of winning \$5M, a 0.89 probability of winning \$1M, and a 0.01 probability of winning nothing. Then one has to choose between A1 and A2, and between A3 and A4. Where A_1, A_2, A_3, A_4 are lotteries.

Table 3.1 The Allais paradox: the common consequence effect

Choice 1	A1	{1 M, 1; 0 M, 0}	A2	{5 M, 0.1; 1 M, 0.89; 0 M, 0.01}
Choice 2	A3	{5 M, 0.1; 0 M, 0.9}	A4	{1 M, 0.11; 0 M, 0.89}

Note outcomes are in Dollars and 1M = \$1,000,000.

Many agents prefer lottery A1 to A2 and prefer lottery A3 to A4. This empirical tendency directly contradicts expected utility theory. According to expected utility theory $A1 \succ A2$ if and only if $1u(\$1M) > 0.10u(\$5M) + 0.89u(\$1M) + u0.01u(\$0)$. Subtracting $0.89u(\$1M)$ from each side, it follows that $0.11u(\$1M) > 0.10u(\$5M) + 0.01u(\$0)$. Adding $0.89u(\$0)$ to both sides, we have $0.11u(\$1M) + 0.89u(\$0) > 0.10u((\$5M) + 0.90u(\$0)$ which holds if and only if $A4 \succ A3$. Thus, from expected utility theory, one can deduce that $A1 \succ A2 \Leftrightarrow A4 \succ A3$. However, many people choose $A1$ over $A2$ and prefer $A3$ over $A4$. This pattern of choice violates the independence axiom and hence the expected utility theory. The Allais Paradox is now commonly known as a special case of a general empirical pattern called the common consequence effect. The name comes from the "common consequence" 1M in gamble 1 and 0 in gamble 2. The independence axiom requires that preferences be unaffected by changes in a common consequence, the Allais Paradox demonstrates that individuals are sensitive to shifts in probability mass. That is according to the independence axiom, an individual's preferences in one event should not depend on the outcome in another event. Thus, it can be shown that violation of the independence axiom explains the observed inconsistencies in the measurement of the vNM utility model. If an agent is an expected utility maximizer then he must prefer A1 to A2 and A4 to A3. Agents may prefer A1 to A2 because they like to be a millionaire with certainty, implying risk aversion. But in choice set 2 the gambles are quite different with a high probability in each lottery of not winning any money. So, the agent may simply choose A3 because the chance of winning \$5M is very similar to the chance of winning \$1M and \$5M is much more. The typical agent responds in a more risk-averse manner in choice set 1 and more risk neutral in choice set 2.

The common ratio effect. Another closely related violation of the independence axiom is the common ratio effect or certainty effect (Kahneman and Tversky, 1979). Individuals are asked to make a choice between the two gambles described in Table 3.2.

Table 3.2 Kahneman and Tversky's choice: the common ratio effect

Choice 1	A1	{$3000, 1; $0, 0}	A2	{$4000, 0.8; $0, 0.2}
Choice 2	A3	{$3000, 0.25; $0, 0.75}	A4	{$4000, 0.2; $0, 0.8}

In the expected utility model it requires that the choice between A1 and A2 has to be compatible with the choice between A3 and A4, i.e. if the more risky alternative A2 is selected in the first choice, the more risky alternative A4 must be selected in the second choice and vice versa. In their experiment using hypothetical payoff outcomes, 80% of the subjects choose A1 over A2 in the first pair of choice and 65% chose A4 over A3. That is, in the common-ratio effect, subjects chose $\$3000$ for sure to a 0.80 chance at $\$4000$ but a 0.20 chance at $\$4000$ to a 0.25 chance at $\$3000$. This pattern also contradicts expected utility, since the first choice implies $1u(\$3000) > 0.80u(\$4000)$, but the second implies $0.25u(\$3000) < 0.20u(4000)$. The independence axiom is violated in this example, since the second pair is constructed by taking 25 percent chance of the first pair and 75 percent chance of receiving $0. The effect gets its name because the ratio of the probability of winning $4000 to the probability of winning $3000 is the same for both choices $(1/0.8 = 0.25/0.2)$.

3.3.2 Violation of the order axiom

In addition to the violation of the independence axiom, there is experimental evidence suggesting that descriptive failures of expected utility may run deeper than violations of the independence axiom (Starmer 2000: 338). The two hidden assumptions in any conventional theory of choice are procedure invariance and descriptive invariance, which constitute another source of weak descriptive power for expected utility. Procedure invariance suggests that preferences over prospects and acts are independent of the method used to elicit them, whereas description invariance stipulates that preferences over prospects are purely a function of the probability distributions and do not depend on how these objects are described.

The most serious blow for the procedure invariance assumption may have been the discovery of preference reversal. Preference reversal, first reported by Lichtenstein and Slovic (1971), describes experimental results that appear to indicate systematic violations of transitivity of preferences. In their experiment subjects were asked to choose between two bets and then to give their true certainty equivalents for the bets in the form of a selling and a buying price. In many cases the subjects set the lowest price for the preferred lottery. In other words, individuals were presented with two gambles, one featuring a high probability of winning a modest sum of money (the P bet), the other featuring a low probability of winning a large amount of money (the

$ bet). The typical finding is that people often choose the P-bet, but assign a larger monetary value to the $-bet. In their 1971 article Lichtenstein and Slovic presented the following pair of gambles (see Table 3.4).

Table 3.4 Preference reversal bets

P-bet	{$4, 0.99; -$1, 0.01}	Expected outcome of the P-bet = $3.95
$-bet	{$16, 0.33; -$2, 0.67}	Expected outcome of the $-bet = $3.94

The P-bet says that 99 percent chance of winning $4 and 1 percent chance of losing $1, the $-bet says that 33 percent chance of winning $16 and 67 percent chance of losing $2. Expected outcomes of the two lotteries are almost the same. The subjects were asked to choose which game they would like to play. Later they were told that they had the ticket to play the bet and were asked to name a minimum selling price for the ticket. Lichtenstein and Slovic found that 73% of the participants consistently have a higher price to the $-bet even though they had chosen the P-bet. The EU theory implies that the bet which is actually chosen also will be the one which will be assigned the largest selling or buying price. In an earlier study Slovic and Lichtenstein (1963) had observed that choices among pairs of gambles appeared to be influenced primarily by probabilities of winning and loosing, whereas buying and selling prices were more highly correlated with payoffs than with probability of winning. Following this observation they argue that, if the method used to elicit preferences affected the weighting of the gamble's components, it should be possible to construct pairs of gambles such that the same individual would choose one member of the pair but set a higher price for the other. This gamble when viewed from the standard theory perspective presents a puzzle. Both choices constitute ways of asking essentially the same question. In these experiments, however, the ordering revealed appears to depend upon the elicitation procedures. Moreover, choice and valuation tasks may invoke a different mental process, which in turn generates different ordering of a given pair of prospects. Consequently, the ranking observed in choice tasks cannot be explained with reference to a single preference ordering (Starmer, 2000: 338).

Framing effect. There is also a long list of experimental observations showing that choice behavior can be dramatically affected by the context in which it takes place. Such evidence contradicts the assumption of description invariance. One of the most persuasive examples reported is due to Schoemaker and Kunreuther (1979) in which the subject has to choose among the same pair of prospects successively framed as prospect and as an insurance decision problem (see Table 3.5.)

Table 3.5 Framing effect.

Choice1: gambling	A	a sure loss of $10	B	1% chance of $1,000 loss
Choice 2: insurance	C	pay an insurance premium of $10	D	remain exposed to 1% loss of $1,000

The two pair of options are stochastically equivalent. The only difference is that choice 1 description presents the information in terms of a sure loss while the information presented in choice 2 is in terms of an insurance payment. Shoemaker and Kunreuther found a very striking difference in response to these two presentations: 51% of the subjects preferred A to B while 81% preferred D to C. This is to say that minor changes in the presentation or framing of prospect can have dramatic impacts upon the choices of decision makers. Thus, it is obvious that expected utility cannot naturally account for such difference.

3.4 The non-expected utility model: Prospect Theory

As mentioned earlier the most commonly accepted model of decision making under risk is the expected utility theory. In the late 1970s the completeness of EU theory in explaining behavior has been challenged. These challenges give rise to the development of competing theories that attempt to explain individual behavior under risk. This section presents one of these alternative theories: prospect theory (PT).

PT was developed first by Kahneman and Tversky (1979). They develop their theory as an alternative to expected utility theory for explaining the outcomes of individual decision making under risk. They argue that choices that individuals make in risky situations exhibit several characteristics that are inconsistent with the basic axioms of expected utility theory. They argued that individuals underweight probable outcomes in comparison with outcomes that are certain. They called this phenomenon the certainty effect. They also pointed out that the certainty effect brings about risk-aversion in choices involving certain gains and risk-seeking in choices involving certain losses (Kahneman and Tversky, 1979).

Kahneman and Tversky (1979) distinguished two sequential phases in a decision process: the editing phase and the evaluation phase. In the editing phase, decision makers contemplate the choice situation and if possible simplify the problem. This includes the operation of coding that is outcomes are coded as gains or losses, prospects are simplified by combining probabilities associated with identical outcomes, and risky components of a prospect are separated from the risk less component of the prospect, and finally components of choices that are common to all prospects are discarded. The edited prospects are then evaluated and the most highly valued risky outcome is chosen. Prospect theory employs two functions: a probability weighting function $\pi(p)$, and a value function $v(x)$. These functions are combined to form the basic equation of the theory which determines the overall value of a prospect. Following is the equation that Kahneman and Tversky (1979) used for simple prospects with the form $(x, p; y, q)$, a gamble between two outcomes (x, y) with associated probabilities (p, q) which has at most two nonzero outcomes:

$$V(x, p; y, q) = \pi(p)v(x) + \pi(q)v(y) \tag{5}$$

When the prospects are strictly positive or negative, the evaluation follows a different rule. In the editing phase the prospects are separated into a risk less (the minimum gain or loss which is certain to be gained or paid) and a risky component (the additional gain or loss which is actually at stake). Thus, if $p + q = 1$ and either $x > y > 0$ or $x < y < 0$, so $\pi(q) = [1 - \pi(p)]$, then,

$$V(x, p; y, q) = v(y) + \pi(p)[v(x) - v(y)] \tag{6}$$

One of the essential features of prospect theory is that the overall value of a prospect is based on changes in a decision-maker's wealth reference point rather than on final wealth states, as in the case of the EU theory. Kahneman and Tversky propose the value function, one of the most widely used components of prospect theory, a function that is commonly S-shaped. It is generally concave for gains (implying risk aversion) and commonly convex for losses (implying risk-seeking), and steeper for losses than for gains (see Figure 3.1).

Another major departure of prospect theory from the EU theory is the treatment of the probabilities. In EU models the uncertain outcome is weighted by its probability, the uncertain outcome in prospect theory is multiplied by the decision weight $\pi(p)$. The weighting function, π, which relates decision weights to stated probabilities, is a monotonic function of p, with $\pi(0) = 0$ and $\pi(1) = 1$, but is not a probability and should not be interpreted as a measure of degree of belief.

According to prospect theory, very low probabilities are over-weighted, that is, the decision weight attached to the rare event is larger than the probability $\pi(p) > p$. Furthermore, prospect theory suggests that for all $0 < p < 1, \pi(p) + \pi(1 - p) < 1$, this is sub-certainty. It implies that as low probabilities are over-weighted, moderate and high probabilities are underweighted, that is the decision weight is smaller than the probability $\pi(p) < p$.

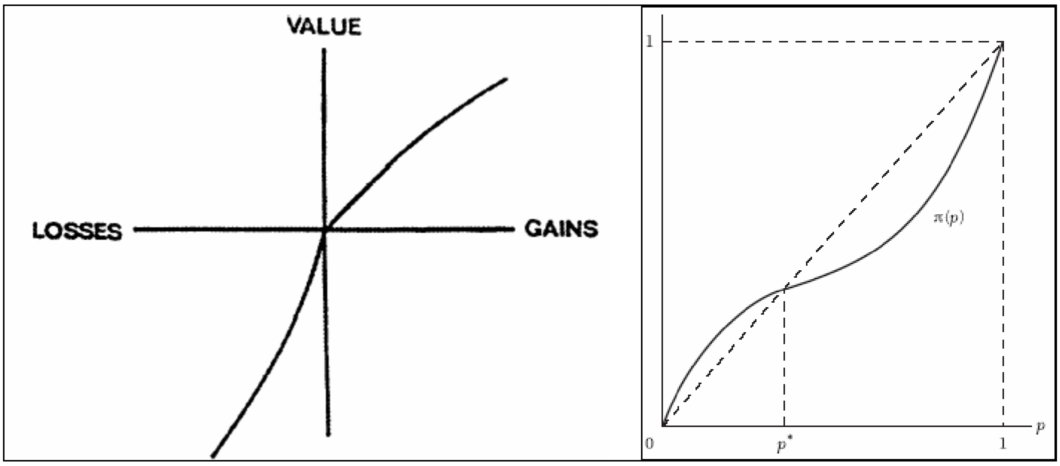

Figure 1 A hypothetical value function and a weighting function (Kahneman and Tversky, 1979: 279)

As in the EU model, values and weights are combined in prospect theory. Outcomes transferred into values by the value function, are weighted by the decision weights and then summed. This summed index is the index by which probability distributions are rank ordered and the subject is assumed to choose the distribution with the highest index (Smidts, 1990). Consider, the choice between the gamble $(x, p; y, q)$, a gamble between two outcomes (x, y) with associated probabilities (p, q): in expected utility maximization theory the value of the utility function is $U(X) = pu(x) + qu(y)$ and in prospect theory the value function is $V(X) = \pi(p)v(x) + \pi(q)v(y)$. In both cases the summed function is maximized and the highest value is chosen. Prospect theory and EU theory coincide when $\pi(p) = p$ for all p and when $u(x) = v(x)$. In this case the expected utility of a lottery defined on $U(X)$ equals the value $V(X)$ of the gamble in prospect theory.

To conclude, prospect theory (Kahneman and Tversky 1979) and its modification, cumulative PT (Tversky and Kahneman, 1992), represent a challenge to EU formulations. PT is widely recognized by economists (Rabin, 2000), as the most comprehensive and best-known alternative to EU models of decision-making. PT's central assertion, which is in clear contrast to the core claim of theories based on the maximization of expected value, is that the value of a possible outcome is not determined by multiplying the utility of this outcome by its estimated probability of occurrence. Instead, the expected value of a prospect is a product of the probability of occurrence adjusted by a probability weighting function and the utility of this outcome filtered through a value function. The core elements of PT's value calculations contradict key tenets of EU theory. By showing that individuals tend to be driven by gains and losses relative to a reference point rather than by final wealth levels. The empirical findings that drive PT, however, offer a more profound challenge to EU models of decision-making. First, the finding that individuals demonstrate a non-linear response to probabilities clearly differs from EU theory expectations. Individual's tendency to underweight moderate and high probabilities means that in these situations their utility calculations will grant more weight to the utility of a possible outcome than to its probability of occurring (the reverse happens when probabilities are overweighted). In contrast, in EU theory individuals possess linear probability functions, utility and probability estimates are given equal weight in the generation of individual's EU values. Second, individuals' attitudes toward risk, and thus their decisions, are likely to change depending on whether the same situation is seen as a gain or a loss (a phenomenon known as preference reversal). This violates EU theory's assumption that people will possess consistent and transitive preferences (Starmer, 2000). So, EU theory assumes that logically identical situations should produce similar results regardless of the frame of reference.

In terms of theory testing, when the evidence shows that individuals (when they operate in loss-frames) consistently engage in risky behavior, this finding, by definition, calls into question the adequacy of those EU theories that are based on the maximization of expected value. When the same individuals switch from risk-seeking to risk-averse behavior when either their domain changes or their probability estimates are in the ranges in which people are likely to overweight the impact of these estimates on their value calculations, EU theories that claim that decision-makers possess convex utility functions are also hard-pressed to account satisfactorily for outcomes. Both these sets of decisions, however, conform to the predictions of prospect theory.

3.5 Discussion and conclusions

In this chapter the expected utility model, which has been the dominant model in explaining individual decision making under risk, and the non-expected model particularly the Prospect Theory was reviewed. It is indicated in the review that the EU model rests on a set of axioms which are considered as logical principles of rational choice. It has also shown that the success of this model is due to its simple and general form, and the bold and testable predictions produced by the model (Starmer, 2000). However, a wave of experimental evidence has been documented which indicates that individuals tend to violate the axioms of the EU model systematically. Schoemaker (1982) concluded that as a descriptive model expected utility theory fails on at least three counts. First, people do not structure problems in a comprehensive way. Second, people do not process information, particularly probabilities, according to the expected utility theory. Third, expected utility theory is a poor predictor of actual choice in laboratory situations.

It can be concluded that prospect theory leads to more accurate descriptions than expected utility theory. Prospect theory is capable of explaining decisions that expected utility theory is incapable of explaining. For example, expected utility theory cannot account for certainty gains, such as the certainty effect that may have a strong influence on individual's decision preferences.

Chapter 4
Decision-Making Under Risk

4.1 Introduction

In semi-subsistence agriculture, farm households face numerous natural, market and institutional risks in generating means of survival. Yield risk, crop price risk, risk of illness and injuries are important risks that prevail in developing economies. Households have developed various mechanisms for coping with risk. These mechanisms offer short-term protection at long-term cost (e.g. diversification versus specialization). As a result, farm households' economic decisions are overshadowed by risk. Their attitude towards risk, therefore, tends to display an explanation for the many observed economic decisions. Knowledge of farmers' attitude toward risk has important implications for the adoption of new farm technologies and the success of rural development programs (Wik and Holden, 1998; Grisley and Kellog, 1987).

In measuring attitude towards risk, two approaches are identified: econometric and experimental. The econometric approach is based on farmers' actual behavioral data, which typically assumes that farmers maximize the expected utility of income. Given a production technology, the risk associated with production and market conditions, the observed level of input use can reveal the underlying degree of farmers risk aversion. Examples of this line of research include (Bar-Shira *et al.*, 1997; Kumbhakar, 2002). The experimental approach is based on questionnaires regarding hypothetical risky alternatives with or without real payments. Here, respondents are asked to choose between lotteries that differ in payoffs and probabilities or both. The experimental approach is further classified into expected utility and non-expected utility approaches.[25] For example Binswanger (1981) measured attitude towards risk in rural India. His approach is embedded in expected utility theory. Humphrey and Verschoor (2004) report an experimental test of individual decision making behavior under risk in rural east Uganda. They find that risk attitude of east Ugandan farmers' exhibit systematic deviations from expected utility theory. Binswanger (1981) measured risk attitude to a set of real payments while Humphrey and Verschoor (2004), used in eight of the twelve decision problems real money payments, however all choice problems were considered as if they were being played for real money (Humphrey and Verschoor, 2004: 67). Real money payments may result in incentive effects and may not reveal the true risk preferences of farmers.

[25] For detail review of expected utility theory and non-expected utility theory (such as prospect theory) see chapter 3 of this thesis.

Using the experimental approach without real payments, this chapter will identify which choice model best describes risk attitude of Northern Ethiopian subsistence farmers.[26] The objective of this chapter is to measure farmers' attitudes toward risk and to see how an individual's attitude toward risk relates to observed characteristics. Specifically this study seeks to answer: (1) does the expected utility theory explains risk attitude of north Ethiopian farmers better than the non-expected utility approach (such as prospect theory)? (2) Are farmers risk-averse to gains and risk seeking to losses? And are there concave utility shapes for gains and convex utility shapes for losses? (3) Are there systematic differences in attitudes amongst farmers? (4) Is there any evidence to suggest that farmer's socio-economic variables determine aversion to risk? From the research questions it is attempted to test whether the farmers made decisions according to the expected utility theory or the non-expected utility theory (prospect theory). Empirical studies on how risk varies across individuals can be useful in predicting households' technology adoption, participation on off-farm work and in crop portfolio selection, since risk and risk aversion behavior plays an important role in these decisions.

In the next section a data set containing farmers' choices of hypothetical binary lotteries are presented. Experimental results on the shape of the utility function and a test of the independence axiom are discussed in section 4.3. In section 4.4 factors affecting risk behavior are econometrically determined. Section 4.5 concludes.

4.2 Data Description

Two year (2001 and 2002) risk assessment data were collected from Tigray. The respondents also participated in a survey on crop production, labor allocation, and consumption decisions. The questionnaire was framed as a farm decision problem. The respondent was the head of the household. Two hypothetical questions, one question without loss and the other question with loss were asked in year 2001. The hypothetical questions asked in the year 2001 were also asked in the year 2002. The purpose of asking in the second year was to stimulate the actual process of decision making and to see whether there is a learning effect in the decision process. Two other additional questions were asked in 2002, which did not involve loss (for details of the questions asked and description of the experimental designs see Appendix 4.I and Appendix 4.II). It is assumed that farmer's choice between the binary hypothetical outcomes was taken as an indication of his/her risk attitude behavior. The two hypothetical questions consisted

[26] As the econometric approach is criticized for confounding risk behavior with other factors that are unrelated to risk preferences such as physical constraints and market imperfections (Just and Pope, 2003: 1255). This is

of two possible outcomes with given objective probabilities, and the respondents were asked to state which of the two option (s)he prefers. It was mentioned that there was no right or wrong answers to these questions. In each year a total of 199 households (i.e., in the two years the panel had a total of 398 observations) participated. It is assumed that by answering the hypothetical questions farmers exhibited their true preferences.

All outcomes of the hypothetical questions are in Ethiopian Birr. In choice 1, for example, the choice is between the safest (certain) option labeled S1 and the riskier option R1 (the probabilistic gain option).[27] The mean is the expected monetary value of the lottery and its standard deviation is denoted by SD. In all of the choice problems the expected mean value of the riskier option is higher than that of the safest option. This can be considered as a control for the behavior of risk-aversion of experimental subjects. Accordingly, each decision problem is considered as a choice between a relatively safe and a relatively risky alternative. It can also be considered that the low variance choice is the safer option and the high variance choice is the riskier option.[28] Farmers opting for the safe option are called more risk-averse than farmers who choose the risky option. The percentage of farmers choosing the safest option for each choice is presented below. For choice 1 most of the respondents choose the certain gain rather than the gamble. This is the certainty effect. Farmers choosing the gamble show risk-seeking behavior. And those who choose the certain outcome show risk-averse behavior.

Choice patterns of farmers in the year 2001 and year 2002

Table 4.1 Choice 1

	Proportion safest choice chosen		Safest option: S1		Riskier option: R1	
	2001	2002	Mean	SD	Mean	SD
S1: (500,1) vs. R1: (1000,0.75) [29]	83.42	81.41	500	0	750	433

Choice 1 S1 offered a 100 percent chance of receiving 500 Birr and R1 offers a 75 percent chance of receiving 1000 Birr. The expected value for lottery S1 is 500 Birr with standard deviation zero. For lottery R1 the expected mean is 750 Birr with standard deviation 433 (for the computation of discrete choice mean and standard deviation see Appendix 4.II). Thus the two lotteries have a relatively large difference in expected values. More than 80 percent of the farmers chose the safest choice in both years (year 2001 and 2002). When farmers are confronted with the

particularly important in Ethiopia where market imperfections are prominent.

[27] In this study safest option means a lottery with lower expected mean value but higher probability of winning the lottery. Riskier option means lottery with higher expected mean and low probability of winning the lottery.

[28] The measure of variability used is the variance of outcomes around the expected mean value.

[29] (x, p) denotes the hypothetical gain x with corresponding probability p .

sure gain and probability gain they tend to choose the sure gain rather than the probability gain. Roughly an equal number of farmers choose the sure gain in year 2001 and year 2002, as choice problem 1 involves no losses.

Table 4.2 Choice 2

	Proportion safest choice chosen		Safest option: S2		Riskier option: R2	
	2001	2002	Mean	SD	Mean	SD
S2: (-500, 1) vs. R2: (-1000,0.75)	49.75	56.78	-500	0	-750	433

Choice 2 is the opposite of choice 1, the sign is reversed so that gains are replaced by losses. Table 4.2 shows that almost half of the farmers choose the sure loss in both years. The mean equality test for the two years choice indicates that there is no significant difference in means (t=0.52). This choice pattern indicates that farmer's preference between negative prospects is not the mirror image of the preference between positive prospects. This finding is in contrast with most of the findings of laboratory experimental studies with students as subjects (e.g. Kahnemans and Tversky, 1979).

Choice patterns in the year 2002

Table 4.3 Choice 3

	Proportion safest choice chosen	Safest option: S3		Riskier option: R3	
		Mean	SD	Mean	SD
R3: (5000,0.25) vs. S3: (2000,0.50)	51.3	1000	1000	1250	2165

In choice 3, about half of the farmers chose the safest choice. Here the safest choice has an expected value of 1000 Ethiopian Birr with a probability of winning equal to 50 percent, while the riskier option has 1250 as expected mean with a probability of 0.25 percent. It seems that half of the sample farmers exhibit risk-seeking behavior. They opt for the gamble rather than for the safest choice.

Table 4.4 Choice 4

	Proportion of safest choice	Safest option: S4		Riskier option: R4	
		Mean	SD	Mean	SD
R4:(9000,0.50) vs.S4: (4500,0.75)	48.7	3375	1949	4500	4500

Similar to choice 3 almost half of the farmers in choice 4 chose the riskier option. In choice 4 the safest choice has low variance (with standard deviation 1949) when compared to the riskier option (with standard deviation 4500). In this choice set about 48.7% of farmers choose the safest choice. However, more than half of the subjects opt for the riskier option, suggesting that subjects were more risk-loving in this choice set.

4.3 Test of the Expected Utility Axiom

4.3.1 Test on the shape of the utility function

Table 4.4 presents the proportion of choice in the gain and loss domain of the utility function. 82% of choices significantly reflect a concave shape for gains. That is poor Tigray farmers are very attracted to a sure gain compared to risky prospects, this is risk-averse behavior (the certainty effect). Furthermore the result for gains confirmed that the utility function is concave which implies that the utility function has a diminishing marginal utility, which is also a well-known empirical finding in the agricultural economics literature. In Enderta and Hintalo-Wajerat, the vast majority, 89% and 76% of subjects respectively, were classified as showing a concave utility for gains. Thus, there were significantly more subjects classified as being concave than convex (the proportion is significant at 5% significance level). In these tests, the null hypothesis states that a concave classification is at least as likely as a convex classification. Tests are therefore two-tailed. As the experimental procedure in elicitation of utility did not use certainty equivalent procedures, linear classifications were not treated here.

Table 4.4 Percentage of concave and convex parts for gains and losses [choice1 vs. choice2]

	Gains			Losses		
	Full Sample	2001	2002	Full Sample	2001	2002
Enderta						
Concave	89	96	82	36	20	52
Convex	11	4	18	64	78	48
Hintalo-Wajerat						
Concave	76	71	81	71	79	62
Convex	24	29	19	29	21	38
Total Sample						
Concave	82	83	81	53	50	57
Convex	18	17	19	47	50	43

The utility shape for losses was also identified. The finding in this case is mixed. In Enderta most (about 64%) subjects exhibit a convex utility function for losses. This empirical finding is consistent with most of the psychology literature findings. It says that losses loom larger than gains, so that people display loss aversion in the domain of losses, resulting in a utility function that is steeper for losses than for gains. Thus Enderta farmers exhibit risk-taking behavior over losses so that a risky loss is preferred to a certain one (i.e. they tend to choose the gamble rather than the sure loss). While in Hintalo-Wajerat a significant proportion (about 71%) of subjects exhibit concave utility for losses. Hintalo-Wajerat farmers' utility function for losses is concave rather than convex. This finding is not according to what prospect theory suggests, in that an individuals value function is convex in losses and much more sensitive to certain losses than to a risky loss. However, Hintalo-Wajerat farmers preferred a certain loss to a risky loss. Therefore loss aversion does not help explaining Hintalo-Wajerat farmers' decision behavior. Here, expected utility maximization would be the appropriate model in explaining and modeling Hintalo-Wajerat farmers' risk preferences.

In Hintalo-Wajerat, the experimental evidence reveals that subjects increasingly inclined to select the safe choice in the domain of gains, the opposite happens in the loss domain (more subjects inclined to be more risk seeking in year 2002 than in 2001). Subjects might realize that the riskier option has a higher expected value than the safer option and become more risk-seeking in the loss domain. This is contrary to what an expected utility maximization would prescribe. In Enderta, in the gain domain the choice is more stable and consistent. However, in the loss domain more subjects' choices converge to a utility maximization hypothesis in the year 2002.

4.3.2 Test on the Independence Axiom

The independence axiom of the expected utility theory requires that if a person chooses a safe option in the gain domain, he must also choose the safe option in the loss domain. If this does not hold the expected utility theory will be violated. To test the independence axiom we only used Choice set 1 and Choice set 2 (see Appendix 4.I for details of the choices offered to farmers).

Table 4.5 reports the choice results for the independence axiom. SS and RR choice responses are consistent with expected utility theory whereas RS and SR choice responses are not (SS response denote the safer S option being chosen in both the first and second choice and RR response denotes the riskier option being chosen in both the first and the second choice problem). In this test the null hypothesis states that the proportion of choice consistent with expected utility maximization (i.e., SS and RR choice) is equal to the proportion of choice consistent with prospect theory maximization (SR and RS).

Table 4.5 Proportion of choice response in the lottery pair (choice 1 vs. choice2)

	Enderta (n=99)					Hintalo-Wajerat (n=100)				
	SS	RR	SR	RS	p-value	SS	RR	SR	RS	p-value
2001	19	3	76	1	0.00 (z=-7.82)	58	8	13	21	0.000 (z=4.53)
2002	46	13	35	5	0.007 (z=2.70)	51	8	31	10	0.011 (z=2.55)

Table 4.6 clearly shows that in Enderta and Hintalo-Wajerat, respectively, 40% and 63% of choice responses is consistent with expected utility theory. In Enderta, subjects choose the sure gain rather than the risky gain in the first choice problem, in the second choice problem subjects prefer the risky loss rather than the sure one. About 79% and 41% of choices in Enderta are not consistent with expected utility maximization in 2001 and 2002 respectively. There is a significant difference of choice proportions between the year 2001 and the year 2002. Learning effects might explain the difference. In Hintalo-Wajerat, although the choice in year 2002 reveals slightly more violations than 2001, the independence axiom does seem to hold.

Table 4.6 Summary proportion of choice consistent with expected utility theory

	Full Sample	2001	2002
Enderta	40	21	59
Hintalo-Wajerat	63	66	59
Total sample	51.5	44.22	58.79

Further Table 4.6 reports that 37% of subjects' responses are contradictory with the expected utility maximization theory in Hintalo-Wajerat. The majority of choice responses are consistent with expected utility theory. Therefore, the expected utility model would be the best descriptor of decision behavior under risk for Hintalo-Wajerat farmers. Moreover, the difference between the proportions of expected utility theory choices in Enderta and Hintalo-Wajerat is significant at the 5% level (t=2.48 with a two-tailed test of a difference in sample proportions based on the normal distribution). It appears that the difference is primarily driven by a higher proportion of risk-averse behavior (i.e., choosing the safest option in both choice problems) in Hintalo-Wajerat than in Enderta (where there is a higher proportion of relatively risk-seeking behavior SR). Thus, expected utility theory does appear to be an appropriate descriptor of risky choices made by rural households in Hintalo-Wajerat. However, in Enderta, the result suggests that risk aversion may be an appropriate assumption in the domain of gains and risk-seeking in the domain of losses.

4.4 Factors Affecting the Risk Attitude of Farmers

It was shown that almost all the farmers surveyed were risk-averse, they choose the safest choice options (see choice 2 to choice 4 in Appendix 4.II). Here, it is important to know the factors that influence farmers' risk attitude. Defining the set of factors that influence risk attitudes is difficult, since many are part of the psychological makeup of the individual. However, there are several observable physical and economic factors that might influence risk attitudes (Grisley and Kellog, 1987).

Empirical model

In order to identify the factors that affect farmers' preferences a binary choice model was used. When several continuous variables are used as explanatory variables in only one choice then estimating a logit model is necessary. The model takes the form (Judge et al., 1982: 521; Greene, 2003: 667):

$$P(SC = 1|x) = \frac{\exp(x'\beta)}{[1 + \exp(x'\beta)]} = F(x'\beta) \qquad (1)$$

where $P(SC = 1|x)$ is the probability that the safest choice is chosen given the full set of explanatory variables x, SC is a qualitative variable with $SC = 1$ indicating that the safest choice is chosen and $SC = 0$ otherwise, x is a $k \times 1$ vector of explanatory variables that are hypothesized to influence the probability of choosing the safest choice, β is a $k \times 1$ vector of coefficients to be estimated, and F is the logistic cumulative distribution function.

Because the sign and magnitude of the estimated coefficients are relative to the response probability, direct estimation of the binary choice model is difficult. It is often more insightful to estimate the marginal effects of changes in the independent variables on the probabilities of choosing the safest option (Judge, et al., 1982: 522; Greene, 2003: 668; Long and Freese, 2003: 139). The marginal effects of changes in each of the k independent variables can be calculated and used to map the impacts on the probability space.

$$\frac{dF(x'\beta)}{d(x'\beta)} = \frac{\exp(x'\beta)}{[1+\exp(x'\beta)]^2} = F(x'\beta)[1-F(x'\beta)]\beta \qquad (2)$$

The dependent variable is a dummy indicating whether the safest choice is chosen.[30] The independent variables are household head characteristics (household age and head education), household size, household wealth (value of livestock which includes value of cattle, camels, horses, mules, donkeys, sheep and goats), year dummy, district dummy, and district mean rainfall. Household size is measured by the number of persons living in the household for at least 9 out of 12 months. Household age is measured as completed years, and head education by a dummy indicating whether the household head is literate. The year dummy captures the differences in rainfall between year 2001 and 2002. The district dummy captures differences in access to markets and other district characteristics. The descriptive statistics of the variables are presented in Table 4.II.

Estimation Results

The results are presented in table 4.7 which includes the values of the logit estimated coefficients, z-statistics, and coefficients of the marginal effects. None of the household head characteristics (age and education) significantly influence risk attitude behavior. It is often assumed that older people are more risk-averse and numerous studies have confirmed this. In this study neither age of the household head, nor head education predict risk preferences. The insignificant results obtained for the household characteristics may indicate that these variables are not exogenous in determining households' risk preferences. The wealth variable (livestock value) is significantly and negatively associated with safest choice. This result is in line with many empirical findings who confirmed that wealthier households are more likely to undertake risky activities (Rosenzweig and Binswanger, 1993). The expectation that wealthier groups should be more risk taking is supported in this study. The result is consistent with Yesuf (2004), who found negative correlations between wealth and risk aversion.

[30] If the respondents choose the safest choice in one of the four choices, then SC takes the value of 1.

Table 4.7 Estimation results and marginal effects of the probability of choosing the safest option[31]

	Coefficient	z-value[32]	Marginal effect
Intercept	-2.02*	-2.30	
Head age	-0.00	-0.01	-0.00
Head education dummy	-0.29	-1.16	-0.06
Family size	0.02	0.34	0.01
Value of livestock	-0.08*	-2.11	-0.02
District dummy (Enderta=1)	-0.74**	-2.98	-0.14
Year dummy (2001=1)	-2.13***	-4.16	-0.48
District mean rainfall	0.04***	3.64	0.01
Log likelihood	-244.01		
LR chi2(8)	53.07		
Number of observation	398		

*Significant at 0.05 significance level; ** significant at 0.01 significance level; *** significance at 0.001 significance level.

The district dummy significantly affects risk-aversion behavior. This result confirms our expectations because Enderta is better-off than Hintalo-Wajerat with respect to the annual precipitation amount, access to markets etc. So, the results suggest that farmers in Enderta are less risk averse than farmers in Hintalo-Wajerat. Finally, the most important variable that predicts risk preferences is the district mean rainfall and year dummy. The year dummy is a good predictor of risky behavior. As 2001 was a good harvest year households were revealed to be more risk taking in year 2001 than in 2002, a bad harvest year.

4.5. Discussion and Conclusions

In this chapter we use experimental data from Enderta and Hintalo-Wajerat two districts in Tigray. A set of hypothetical questions on lotteries were asked to farmers. Using the answers to these hypothetical lottery questions, we investigated: (1) whether farmer's preferences are consistent with expected utility theory or prospect theory, (2) whether farmers are risk-averse to gains and risk seeking to losses and have concave utility for gains and convex utility for losses, and (3) whether there is any relationship between farmer's socio-economic variables and farmer's risk preferences. In the experiment it is said that farmers opting for the safe option are called more risk-averse than farmer who choose the risky option.

The result indicates that more than 80 percent of the farmers chose the safest choice. When farmers are confronted with the sure gain and probability gain farmers tend to choose the sure gain rather than the probability gain. This is the certainty effect. However, when farmers are

[31] The marginal effect for a dummy variable (such as year dummy and the district dummy) is from 0 to 1.
[32] Z-value is the value of the coefficient estimate divided by its standard error.

confronted with sure loss and probabilistic loss, about 53 percent of farmers choose the safest choice (i.e., the sure loss) rather than the probabilistic loss. This finding is in contradiction with the findings of Kahneman and Tversky (1979). With respect to the shape of the utility function the findings are mixed. In Enderta about 64 percent of the subjects exhibit a convex utility for losses. This finding is consistent with most of the psychology literature findings. Prospect theory or loss-averse behavior is the appropriate model for explaining Enderta farmer's risk attitude. While in Hintalo-Wajerat a significant proportion of choice (about 71%) of the subjects exhibit concave utility for losses. This is in contrast to what prospect theory suggests. Here, expected utility maximization would be the appropriate model in explaining and modeling Hintalo-Wajerat farmer's risk preferences. None of the household head characteristics (age and education) have a significant influence on the risk attitude behavior of Tigray farm household heads. However, district dummy, district mean rainfall, and household wealth significantly influence risk preferences of farmers.

The caveats of risk analysis in this chapter are: first, we used a simple hypothetical question, which was framed as a farm decision problem. More complex and advanced utility elicitation techniques, such as Trade Off method can also be used in surveys, and therefore, remain a future research option (for the Trade Off Method see Fennema and van Assen, 1999). Second, we examined the risk-attitude of the head of the household. We ignored risk-attitude of the spouse.

Appendix 4.I Hypothetical questions

The hypothetical questions offered to the farmers where:

Choice 1. If you are given the choice between A and B which option would you select?

1. A sure gain of 500 Birr.
2. A risky prospect that offers a 75 percent chance of winning 1000 Birr and a 25 percent chance of winning nothing.

Choice 2. If you are given the choice between A and B which option would you select?

1. A sure loss of 500 Birr.
2. A risky prospect that offers a 75 percent chance of losing 1000 Birr and a 25 percent chance of losing nothing

Choice 3. If you are given the choice between A and B which option would you select?

1. A sure gain of 2000 Birr.
2. A risky prospect that offers a 25 percent chance of winning 5000 Birr, a 50 percent chance of winning 2000 Birr and a 25 percent chance of winning nothing.

Choice 4. If you are given the choice between A and B which option would you select?

1. A risky prospect that offers a 25 percent chance of winning 5000 Birr and a 75 percent chance of winning nothing.
2. A risky prospect that offers a 50 percent chance of winning 2000 Birr and a 50 percent chance of winning nothing.

Appendix 4.II Experimental Design and questionnaire

A hypothetical questionnaire was developed using 25 test interviews to ensure that the hypothetical questions would be interpreted correctly. All the interviewers had prior experience and received two days training. Because of their district background and two time contact with the farm households, we believe that the effect of interviewer bias could be minimized. In the experiment, subjects were offered with four sets of hypothetical choices, involving no real money payment. A total of 398 subjects participated in the experiments. To minimize the order effects, the hypothetical questions were randomly arranged and randomly offered to the respondents. The hypothetical questions offered can best be understood by examining the pair of lotteries in table 4.I.

Table 4.I Descriptive statistics of proportion of choice response in the lottery pairs by year.[33]

Questions	Proportion safest		Safest Option		Riskiest Option	
	2001	2002	Mean	SD	Mean	SD
Choice1 S1: (500,1) vs. R1: (1000,0.75)	83.40	81.40	500	0	750	433
Choice2 S2: (-500,1) vs. R2: (-1000,0.75)	49.70	56.80	-500	0	-750	433
Choice3 S3: (2000,1) vs. R3: (5000,0.25; 2000,0.50)		77.40	2000	0	2250	1785
Choice4 R4: (5000,0.25) vs. S4: (2000,0.50)		51.30	1000	1000	1250	2165

Note: (x, p) denotes the hypothetical gains x with corresponding probability p and zero otherwise.

As indicated in the data description section of this chapter, S and R correspond to the safest and riskier choice respectively. We call the low variance lottery the safe option and the high variance lottery the risky option. For example in the year 2001 about 83.4% of subjects chose the safest option.

Table 4.II Descriptive statistics of household characteristics

Variables	Mean	Standard deviation	Min	Max
Age of head	51.82	11.90	22	83
Family size	5.95	2.19	1	11
Head education dummy (=1 if literate)	0.37	0.48	0	1
Value of livestock	3596.94	3941.48	0	25200
Household income (farm and off-farm) Ethiopian Birr	3043.71	2539.51	104	20579

[33] For the discrete hypothetical choice variable the expected mean is computed by the sum of the products of the hypothetical gains x multiplied by their respective probabilities p. $E(x) = \sum x(p)$, where $E(x)$ is the expected mean. The variance of the discrete hypothetical choice is equal to the sum of the squared deviations of the hypothetical gains x from their expected hypothetical mean value multiplied by the respective probabilities of the value of x. That is, $\text{var}(x) = \sigma_x^2 = \sum (x - E(x))p$ (Pindyck and Rubinfeld, 1998).

Chapter 5
Determinants of Crop Mixes Grown on Household Farms

5.1 Introduction

It is well known that households in semi-arid areas often experience rainfall-related shocks that result in low and uncertain incomes (Dercon and Hoddinott, 2003). A large body of literature explores the ex-ante and ex-post responses to these shocks. One line of literature examines how households respond to these shocks ex-post. Udry (1995) assesses the extent to which saving allows households to smooth consumption, Fafchamps, *et al*. (1998) and Dercon (1998) focus on the role of livestock holdings as a means of smoothing consumption, and Kochar (1999) on the role of off-farm labor supply as a response to income shocks. A second line of research looks at the effectiveness of ex-ante income smoothing strategies in reducing fluctuations in income. Dercon (1996), Larson and Plessmann (2002), and Morduch (2002) find evidence that farmers choose to diversify into less profitable crops or choose less productive technology.

In the absence of credit and insurance markets for insuring risk ex-post against adverse shocks, many farm families depend directly on diversity of their crops for the food and fodder they use (Benin *et al*., 2004). For example, diversification of crops grown in Tigray is often considered as a precaution against rainfall risk. Moreover, risk attitudes of farmers have also shown to influence crop choice and input allocations (Ramaswami, 1992; Isik, 2002).

In recent years using Pakistan, Punjab data Kurosaki and Fafchamps (2002) examined farmers' crop choices in the presence of price and yield risk. They conclude that even in well-developed markets, crop choices are dependent on risk. Woldehanna (2000) addresses the relationship between off-farm income and crop choice in Tigray. He pointed out that off-farm income and agronomic conditions heavily influence crop choices. Rainfall is highly variable in Tigray and it is of importance to analyze the effect of rainfall risk on crop choice. Prior to the realization of rainfall we assume households know the distribution of rainfall overtime. A key question here is how crop choice is influenced by rainfall risk. Understanding farmers' crop choices and land allocation decisions in drought prone areas are important in identifying the factors that determine farmers' crop choices decisions. Therefore, this chapter examines the impact of risk on the probability of growing crops and on the allocation of land to crops. Specifically the following questions will be addressed: (1) Does rainfall variability has a significant effect on the crops grown and land allocation decisions to each crop? (2) Do farmers' risk attitudes affect farmers' crop choices and land allocation decisions? (3) Do socio-economic variables of households determine crop choice?

To answer the research questions, a crop choice model was specified and estimated using probit estimation. Moreover, a land allocation model was specified and estimated using the seemingly unrelated regression method. Rainfall risk was incorporated in the models. The models are applied to a four-year panel data of two districts in Tigray.

The rest of the chapter is organized as follows: section 5.2 presents a literature overview on crop choice and risk. The theoretical model is presented in section 5.3. Section 5.4 describes the data used. Section 5.5 presents the empirical model and estimation methods. Estimation results are presented in section 5.6. Section 5.7 concludes.

5.2 Cropping Systems and Risk: Literature Overview

Central to a household's production decision whether to choose one crop to another is an assessment of the degree of variability in yield and chance of income loss from doing so (Chavas and Holt, 1996). Because of the inter-linked relationship between production and consumption, the household's decisions relative to a particular activity are likely to include consideration of the income variability impact of that activity on household consumption levels. To the extent that ex-post consumption risk is imperfectly insured, a farmer's ex-ante crop production choice will be affected by ex-post consumption. In addition, decisions in any particular crop will be made within the context of the household's multiple crop production activities, with the consideration of risk associated with it (Dercon, 1996).

Risk from rainfall variability is a major limiting factor to crop production in Ethiopia. This problem is more exacerbated in the northern regions where drought is a common phenomenon and can lead to consumption shortfalls and result in acute food insecurity for millions of people particularly for rural households. Variability also arises because of the influence of changing production practices and weather related development of plant diseases and pests.

Faced with such risk, farmers have been highly risk-averse (Kebede, 1991; Binswanger, 1980). Under these circumstances and in the absence of insurance markets, most farmers use ex-ante risk minimizing strategies to reduce variability in crop yield. In analyzing the risk-return tradeoffs a farmer must consider the expected return to different choices and the variance in return. Farmers can respond to risk by altering their crop mixes; output levels; input use or a combination of them. Research indicates that greater yield risk results in lower levels of both input use and final output (Chavas and Holt, 1990; Dercon, 1996).

Traditional risk management practices can be used to reduce yield and, hence income risks. Such practices involve diversification in crop production, crop variety selection, fertilizer input and timing of activities. These options are usually undertaken before and or during a particular season. Crop rotation is also used as a means to conserve soil fertility by planting legumes one year and non-legumes (e.g. cereals) the following year in the same field (Amede *et al*., 2001). Thus, crop sequencing affects the entire soil-plant ecosystem by altering the quantity and quality of organic residues returned to the soil, the soil moisture reserve, the erodibility of soil and the availability of nutrients. It is therefore an important technique in improving soil fertility and moisture content (Amede *et al*., 2001). Cereals such as teff, wheat or barley (one year or two successive years) are traditionally grown in rotation with legumes. Furthermore, crop rotation will depend on soil and rainfall pattern, preferences toward risk, expected price of outputs, and the availability of labor (Corbeels *et al*., 2000). Rotation reduces intra-yield fluctuations because a low return in one year for one crop is combined with relatively high returns from a different crop.

Inter-cropping, incorporating two or more crops in the same field at the same time, is also a traditional way to restore soil productivity thereby enabling the maximum returns to be obtained from the cultivated land under uncertain conditions (Corbeels *et al*., 2000). Inter-cropping also provides consumption insurance, as some crops are likely to give a fair return even if bad weather causes the partial or total failure of the others. It has also an advantage in reducing potential pests and diseases, which reduces needs for purchases of chemicals to control pests (Amede *et al*., 2001). Planting short season varieties that mature earlier in the season, protecting against the risk of moisture shortage and yield loss is also a common agricultural practice of farmers. By diversifying crops, households will have relatively less of a chance of suffering a major crop failure if only one of the crops should fail to bring the expected returns.

Although climatic and agronomic factors are limiting crop choice, it appears that seasonal shortage of labor also plays a role in crop choices (van den Berg, 2001). This will depend on the time spent on agricultural work at peak periods and on whether there is flexibility in the farming systems exploited. Consequently, farmers frequently adapt their cropping patterns or the timing and nature of their operations in a way that reduces these labor peaks when there is a felt pressure on labor (Woldehanna, 2000; van den Berg, 2001). The attempts made by farmers to reduce seasonal peak labor demands include adjustments of the crop mix to achieve greater complementarity in labor use.

Moreover, farmers risk attitude also affects the probability of growing crops or crop mix and land allocation decisions. For example, risk-averse farmers might devote more land to a staple and home consumed crops and less land to a cash crop when compared to a risk-neutral land allocation (Chavas and Holt, 1990). In the study areas about 85% of farm households have chosen to plant barley, which is mainly a staple food and 4% have chosen to plant lentil, which is a commercial crop. As farm households are both producers and consumers of their own produce, they have to worry about price fluctuations not only as producers but also as consumers. But the main emphasis is still on subsistence production.

Another important mechanism for dealing with crop income risk is the use of off-farm labor supply in the daily wage labor market. Previous research has found that the supply of labor in the off-farm labor market is an important method for smoothing income in the presence of negative shocks to farm production (Kochar, 1999; Rose, 2001). This suggests that farmers may use the off-farm labor market to smooth income in case of crop failure. Off-farm income of the households might positively affect crop production by reducing the liquidity constraints at the beginning of the agricultural season. If for example, there is binding credit constraint that limits the use of fertilizer by farm households, then off-farm work might be a way of relaxing those credit constraints. If a farmer's expectation of rainfall variability would be high at the beginning of the agricultural season, this would adversely affect the prospects of the crops grown, potentially lessening the labor required for crop production. On the other hand, higher levels of involuntary unemployment in the off-farm labor market would cause farmers to allocate more labor to on-farm production and less to off-farm work. On the contrary, lower levels of involuntary unemployment in the off-farm labor market would cause farmers to allocate more labor to off-farm and less labor to on-farm activities. So, farmers could use the off-farm labor market as a tool for income smoothing enabling them to smooth consumption ex-post in the face of negative production shocks.

Differences in resources such as availability of oxen have an effect on timely plowing of plots and on crop mixes as well. Access to markets is among the most important factor that might affect crop choice. Proximity to urban sectors might favor the production of cash crops such as teff and lentil over subsistence crops such as grass pea. Human capital assets are another major determinant of crop choice.

Numerous factors impose risks on crop choice (including rainfall variability, floods, pests, labor shortage, off-farm income, resource availability, proximity to markets, and price fluctuations). Among these factors, the effect of rainfall conditions on agricultural production is significant. A close relationship exists between crop yield and moisture stress and therefore crop mix may be a reliable indicator of rainfall variability or drought management practices. Thus crop mix is the outcome of natural (soil type rainfall amount in the growing season), physical (such as labor, oxen and capital), individual characteristics (age, gender, education), household characteristics (household composition), and village level characteristics (distance to markets and off-farm employment opportunities).

5.3 Theoretical Model

A household model was developed to investigate the relationship between crop choice and rainfall variability and socio-economic characteristics. The model draws upon the economic theory of farm households (Singh *et al.*, 1986). The model explicitly accounts for the fact that farm households in Tigray are both producers and consumers of their own agricultural products. As a result, production decisions are influenced by consumption needs, so that production and consumption decisions in the model are assumed to be made jointly in response to rainfall uncertainty.

It is assumed that agricultural households maximize the expected utility of profit $(EU(\pi))$, where π is profit and E is the expectation operator. Assume that farmer's utility function is a von-Neumann Morgenstern utility function, which is concave, continuous and differentiable function of profits, thus $U'(\pi) > 0$ and $U''(\pi) < 0$. Outputs are assumed to be stochastic. This assumption seems plausible, as rainfall risk is the major source of uncertainty in crop production in northern Ethiopia. Further, let Y_i (the output produced on the farm of crop $i, (i = 1,..., N)$ be a random variable with subjective probability density function $f(Y_i)$ reflecting farmer's output expectations. A farm household allocates his total size of land (A) to i crops mainly: wheat (A_W), teff (A_T), barley (A_B), grass pea (A_V), and lentil (A_L).

The farmer's utility maximization problem can be represented as follows:

$$U^*(\pi) = \max_{H_i^F, X_i, K_i, A_i} EU\left(\sum_{i=1}^{N} P_i \times Y_i (H_i^F, X_i, K_i, A_i; G, Z, \theta - \sum_{i=1}^{N} W \times X_i \right)$$
$$s.t \sum_{i=1}^{N} A_i = A \qquad \text{and} \qquad \mathrm{A_i} \geq 0 \tag{1}$$

where $U^*(\pi)$ is the optimized utility from farm profit π, P_i is the output price of crop i; H_i^F, farm labor supplied to crop i[34]; X_i is a vector of variable inputs (seed, fertilizer, and pesticide) used in producing crop i; K_i is vector of capital goods (value of livestock and value of farm

[34] On-farm labor supply is proxied by the number of adults (aged 15-65) in the household.

equipment) used in the production of crop i; A_i is the amount of land used in the production of crop i, A total amount of land cultivated; G is vector of household characteristics, Z is vector of district level characteristics (such as market opportunities). Moreover, output Y_i is assumed to be a function of rainfall variability (θ). W is the vector of prices of variable inputs. $\sum_{i=1}^{N} P_i Y_i$ represents the expected total revenue from N crops produced on the farm and $\sum_{i=1}^{N} WX_i$ represents the total variable cost of production.

In the utility maximizing optimum the shadow price (value marginal product) of land should be equal for all crops cultivated (for crops not cultivated it is equal or less than 0). The shadow price of land can be found by differentiating the expected utility of profit with respect to the quantity of land allocated to crop i:

$$\frac{\partial EU(\pi_i)}{\partial A_i} = P_i \frac{\partial Y_i}{\partial A_i} - \lambda = 0 \quad \Rightarrow \quad \lambda = P_i \frac{\partial Y_i}{\partial A_i} \tag{2}$$

Where λ is the shadow price of land.
The shadow price of land in equation (2) is among other things determined by rainfall variability, household characteristics, and market characteristics.

Taking the inverse of the shadow price equation yields the optimal amount of land allocated to crop i:

$$\begin{cases} A_i = f(P_i,\ldots,P_N,W,H_i^F,A,K_i,G,Z,\theta) & \text{if} \quad \lambda > 0 \\ A_i = 0 & \text{if} \quad \lambda \le 0 \end{cases} \tag{3}$$

The optimal amount of land allocated to crop i is a function of all variable input prices, expected output prices, on-farm labor supply, total cultivated land size, capital, and rainfall variability. The amount of land allocated to each crop is also a function of household and village level characteristics.

Economic theory states that a risk neutral farmer will allocate its land such that expected marginal returns (shadow prices) are equalized across crops. When expected return of the land allocated to one crop is greater more land is allocated to that crop and less will be allocated to the rest of the crops. However, if farmers are risk-averse and the expected utility of choosing one crop to be grown is greater then more land is allocated to this crop. Here it might be the case that farmers may be willing to accept lower returns by choosing less risky crops.

5.4 Empirical Model and Estimation

In this section the empirical model of crop choice and the land allocation model are presented. It is hypothesized that if the expected marginal utility of one crop is greater than of another crop more land is allocated to this crop.

Crop Choice Model

The crop choice model is binary and models the probability of choosing a crop to be planted. Equation (3) is used to derive the crop choice model.

$$P(I=1|y) = F(y'\delta + v > 0) \tag{4}$$

$$I = 1 \quad if\ I^* > 0$$
$$= 0 \quad \text{otherwise}$$

Where I^* is an unobserved latent variable. What is observed is a dichotomous variable I, which takes the value of 1 if crop i is chosen to be planted on the specified plot and zero otherwise. y is a vector of independent variables that are hypothesized to influence the choice of crops to be planted, δ is a vector of parameters F is the distribution function, v is a normally distributed error with zero mean and variance σ_v^2.

Land Allocation Model

The dependent variable in the land allocation model is the land allocated to each crop. Then the observed allocation can be denoted as:

$$A_i^* = x'\beta + u \tag{5}$$

Where A_i^* is a latent variable that is observed for values greater than 0 $I = 1(I^* > 0)$) and is censored for values less than or equal to 0. x is a vector of exogenous variables that are hypothesized to influence the land allocation decision, β is a vector of unknown parameters and u is a normally distributed error with zero mean and variance σ_u^2.

Equation (5) involves a system of seemingly unrelated regressions where contemporaneous correlations across equations are assumed.[35] This is a reasonable assumption in that the parameters of the model are shared across equations and land allocation decisions for one crop are likely to be related to those about others. In this situation, Ordinary Least Squares estimation would result in inefficiency, as it would ignore the correlation of error terms across equations (Greene, 2003: 341). For efficient estimators, Zellner's estimation technique for seemingly unrelated regressions (SUR) (Zellner, 1962) is employed.

5.5 Data

A Tigray farm household survey is used to estimate the model developed above. The dataset was collected in 1996, 1997 2001, and 2002 covering four years. Among others the data consists of information on household use of farm inputs (such as variable and quasi fixed inputs), household characteristics, and rainfall.

In the crop choice model (equation 4) the dependent variable is the probability of choosing crops to be grown. It is a binary indicator of whether the crop is chosen to be grown or not (for details on the farmers' choices for each crop, see Appendix 5.II). The dependent variable for the land allocation model (equation 5) is the proportion of land allocated to the specific crops. It measures the proportion of land allocated to each crop.

The independent variables included in the two models are variable output prices, input prices (seed, fertilizer, and insecticides), family size, total cultivated land size, capital (value of livestock and value of farm equipments), rainfall risk, household head age, village district characteristics, and year dummies for the years 2001 and 2002. The variable input prices are computed by dividing the value of the inputs by the amounts used for each crop. Family size is the number of adult (aged 15-65) members in the household. Total cultivated land is measured by the sum of rented and owned cultivated land. Value of livestock includes value of cattle, horses,

[35] In the presence of rainfall risk and/or nonseparability of consumption and production decisions joint management of all crops is assumed. Thus estimation of equation (5) for each crops separately will waste the information that the same set of parameters appears in all the equations (Greene, 2003: 340)

mules, camels, and donkeys. Value of farm equipment includes value of traditional oxen plough equipment, sickles, hoe etc. Household characteristics (include age and education of the household head and off-farm income). Age is measured as completed years. For education an education dummy is used indicating whether the household head is literate or not. The district dummy captures differences in access to markets and other district characteristics. The year dummies capture the differences in rainfall. The major aim of this chapter is to estimate crop choice under rainfall shocks. The crop choice and land allocation model include rainfall variability, which is measured by the coefficient of variation of the main crop rainy season, which is the standard deviation divided by the mean.[36] Because of the disproportionate importance of the main rainy season, variability in the main cropping season '*keremet*' is a significant factor in governing crop choice and land allocation decisions. The mean and standard deviations of the variables used in the analysis are reported in Appendix 5.I.

5.6. Results

Crop-Choice Model

Estimation results for the probability of choosing a crop to be planted are presented in Table 5.1 showing the marginal effect (the effect of a unit change in each independent variable on the probability of growing that particular crop, holding the other factors constant).[37]

Rainfall variability has a significant negative effect on the probability of growing wheat and lentil. The marginal effect indicates that if rainfall variability increases by 1 unit, probability of growing wheat and lentil crop decreases by 0.13 and 0.10 respectively. It is known that wheat and lentil are very sensitive to rainfall variability. For teff, barley and grass pea the effect of rainfall variability is positive and significant. If the rainfall condition is not promising then, teff barley and grass pea are planted in August.[38] The marginal effect indicates that the probability of growing teff, barley and grass pea increases by 0.25, 0.12 and 0.42 respectively if rainfall variability increases by 1 unit.

[36] Unlike the variance and standard deviation, the coefficient of variation is not sensitive to scaling. Hence it is more useful to capture the variability of rainfall.
[37] The marginal effect for a dummy variable (such as year dummy and the district dummy) is from 0 to 1.
[38] It is evident that barley, *Sa'sa* variety and the teff variety which only require 45 days to mature are likely to yield more stable returns than wheat under extreme rainfall variability.

Table 5.1 Marginal effects of the probability of growing a crop (z-value in parenthesis)[39]

Variable	Wheat	Teff	Barley	Lentil	Grass pea
Price of output	0.02*	0.01***	0.01***	0.03***	0.01***
	(2.42)	(10.55)	(15.79)	(5.80)	(4.13)
Price of seed	-0.01***	-0.00	0.02*	0.01	-0.00
	(-5.32)	(-1.10)	(2.55)	(1.94)	(-0.25)
Price of insecticide	-0.01	-0.03*	-0.02		
	(-0.45)	(-2.29)	(-1.03)		
Price of fertilizer	-0.03**	0.01	-0.00*		
	(-2.67)	(0.11)	(-2.16)		
Family size	0.09**	0.03***	0.02***	0.01	-0.04**
	(2.71)	(4.46)	(3.62)	(1.04)	(-3.01)
Head age	0.01	-0.01	0.01	-0.01	-0.01
	(0.93)	(-1.70)	(0.30)	(-1.07)	(-1.72)
Total land cultivated	0.05	0.07**	0.04*	0.01	0.03*
	(0.86)	(3.06)	(1.16)	(0.50)	(2.44)
Value of livestock	0.05***	0.06*	0.04**	0.01	0.02
	(3.92)	(2.04)	(3.27)	(1.15)	(0.76)
Coefficient of variation of rainfall	-0.13**	0.25**	0.12***	-0.10	0.42**
'*keremet*'	(-2.79)	(3.23)	(3.50)	(-1.92)	(3.15)
Year dummy for year 2001 (2001=1)	0.62***	0.01	0.03	0.02*	-0.03
	(4.26)	(0.16)	(1.82)	(2.52)	(-0.48)
Year dummy for year 2002 (2002=1)	-0.73***	0.32*	0.04*	-0.04	0.06***
	(-4.99)	(2.55)	(2.10)	(-1.68)	(6.69)
District dummy	0.10	0.11***	-0.03*	0.11*	-0.08
	(0.60)	(3.93)	(-2.00)	(2.46)	(-1.56)
Constant	-0.64***	-0.20***			
	(-5.74)	(-3.30)			
Number of observations	796	796	796	796	796
LR chi2	281.46	282.86	223.14	130.46	163.39
Log likelihood	-328.19	-378.37	-298.41	-217.72	403.87
F(12,784)	10.60	28.99	69.71	10.22	16.96

*Significant at 0.05 significance level; ** significant at 0.01 significance level; *** significance at 0.001 significance level.

The effect of value of livestock on the probability of growing crops is positive for all crops and significant for the major crops, wheat, teff and barley. The result suggests that livestock is important in providing draft power for plowing, threshing and transporting crops. Cultivated land size positively and significantly increases crop choice for the five crops. This indicates that farmers who have access to large amounts of farmland tend to diversify crops. The effect of family size on the probability of choosing crops to be grown is as hypothesized, positive and significant for the probability of growing wheat, teff, and barley. Teff and wheat are the most labor demanding crops. On the other hand family size is negatively and significantly related to the probability of choosing grass pea crop. If family size increases by one unit the probability of growing grass pea decreases by 0.04. This suggests that availability of more family member encourages farm households to supply more labor to off-farm activities which leads to increases

[39] The variable value of farm equipment was initially included in the model. The initial estimate was not significantly different from zero for the five crops, suggesting that almost all farmers own the same quantity of

in the probabilities of choosing less labor demanding crops such as grass pea. The household head age coefficient is negative and significant for the probability of growing teff, lentil and grass pea and positive for the probability of growing wheat and barley.

The probability of growing wheat and teff crop reduces if the price of seed input increases. If farmers do not have the required amount of wheat and teff seed at their disposal for planting they have to buy these seeds, with increased seed prices purchasing of these seed inputs in the planting period falls. However, the price of seed positively influences the probability of growing barley and lentil. In the study areas it is a common practice that farmers keep barley for planting in the following years, as barley is the most important staple food grain. The effect of output prices on the probability of growing crops is positive and significant for all crops. The rationale behind this finding is that increases in output prices will encourage farmers to increase output. The year dummies are a good predictor of farm households' crop choices. A good rainfall year increases the probability of growing all crops except grass pea. The year dummy for 2001 is positively and significantly related to wheat and lentil. The year 2001 was a good rainfall year and farmers were encouraged to plant wheat and lentil. The year 2002 was a bad rainfall year and hence farmers were opting for planting teff, barley, and grass pea (for details on yearly rainfall data see Chapter 2: Appendix 2.I). Being in the Enderta district positively and significantly influences the probability of growing teff, and lentil.

Land Allocation Model

Seemingly unrelated regression estimation results for the proportion of land allocated to each crop are presented in Table 5.2.

As expected, rainfall variability negatively influences the allocation of land to wheat and lentil. The amount of land allocated to wheat and lentil production are more responsive to a unit change in rainfall variability. A 1 unit increase in rainfall variability reduces the proportion of land allocated to wheat and lentil by 0.16, and 0.07 respectively. This is due to the fact that wheat and lentil are very sensitive to the variability of rain. If rainfall conditions are poor then the amount of land allocated to wheat and lentil will decline, these crops only grow well when rainfall is relatively high and reliable.[40]

The effect of rainfall variability is as expected, positively and significantly related to the amount of land allocated to teff, barley and grass pea. The result shows that a 1 unit increase in

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oxen plough equipments, sickle and hoe, which cause insufficient variability in the data. Therefore farm equipment was omitted from estimation.

[40] Wheat and lentil are long-day plants, after planting they are ready to be harvested after 80-120 days. Hence they are more sensitive to rainfall variability.

the variability of rainfall increases the proportion of land allocated to teff, barley and grass pea by 0.14 and 0.39, and 0.05 respectively. When the June and July rains fail, or the gap between rainy seasons is too long for the crops to survive, short-growing season teff, barley and grass pea are planted in August. This implies that the proportion of land allocated to crops is adjusted according to the rainfall conditions. That is plots can be replanted with drought resistance crops if the rainfall amount is not reliable. The fastest-growing varieties of teff and barley, which farmers have at their disposal are planted in August, which can be matured in 45 days using limited soil moisture.[41] Moreover, grass pea is a well-known legume crop that can survive under extreme rainfall variability. Whenever rainfall is insufficient or highly variable farmers show flexibility in their land allocation decisions. This kind of flexibility plays a critical role in reducing the cost of rainfall variability to farmers. For this reason, when farmers expect high variability in rainfall and experienced an insufficient rainfall amount later in the cropping season (August) they allocate more land to grass pea, barley, and teff.

Family size positively and significantly influences the proportion of land allocated to wheat barley and teff.[42] A one unit increase in the family size increases the proportion of land allocated to wheat barley and teff by 0.04 0.05, and 0.18 respectively. As hypothesized teff, wheat, and barley demand more on-farm labor for land preparation, weeding, threshing and harvesting (see Appendix 5.II). Family size negatively influences the proportion of land allocated to grass pea. Here family size and grass pea production are substitutes. This crop requires relatively low labor input for production. If more adult labor is available in the household less labor is devoted to grass pea production and more to off-farm employment. Although the decision of land allocated to each crop is thought to be dependent on the value of livestock, except for the share of land allocated to barley, for four of the crops the value of livestock is not statistically different from zero.

[41] The performance of teff and barley under less moisture is improved by an appropriate choice of teff and barley varieties. The '*wafe taff*' variety of teff and the 'sa'esa' variety of barley are short-season varieties and perform well under poor soil moisture conditions. Short growing period teff, barley and grass pea are capable of giving higher yields under large rainfall variability than any other crops.
[42] This finding is consistent with Woldehanna (2000). He founds that family size positively influences the share of land allocated to wheat, teff, and barley (Woldehanna, 2000: 169).

Table 5.2 Seemingly unrelated regression estimation of the proportion of land allocated to crops (t-values in parenthesis)[43]

Variable	Wheat	Teff	Barley	Lentil	Grass pea
Price of seed	-0.23***	-0.20***	0.02***	0.23**	-0.20
	(-3.92)	(-4.90)	(6.21)	(2.94)	(-1.52)
Price of insecticide	-0.01	-0.03*	-0.02		
	(-0.63)	(-2.29)	(-1.03)		
Price of fertilizer	-0.02	0.02	-0.05*		
	(-1.21)	(1.42)	(-2.41)		
Family size	0.04**	0.18*	0.05*	0.31	-0.07
	(2.62	(2.19)	(2.40)	(1.44)	(-0.42)
Head age	-0.01	0.01	0.19*	-0.16	0.18*
	(-0.71)	(0.15)	(2.38)	(-1.58)	(2.13)
Total land cultivated	0.40***	0.60***	0.46***	0.41***	0.11***
	(6.94)	(8.03)	(9.28)	(3.53)	(8.67)
Value of livestock	0.12	0.02	0.02*	0.03	0.08
	(1.20)	(0.67)	(2.02)	(1.12)	(1.03)
Coefficient of variation of '*keremet*' rainfall	-0.16*	0.14**	0.39**	-0.07	0.05*
	(-2.04)	(2.93)	(2.69)	(-0.39)	(2.19)
Year dummy 2001 (2001=1, 0 otherwise)	0.03***	0.03	0.03*	0.01	-0.07
	(3.63)	(2.33)	(2.08)	(0.20)	(-1.90)
Year dummy 2002 (2002=1, 0 otherwise)	-0.05***	0.04**	0.01	-0.10*	0.03
	(-4.04)	(2.95)	(0.73	(-2.37)	(0.78)
Dummy woreda	0.04**	0.08***	0.03	0.04***	-0.13*
	(2.60)	(3.53)	(1.17)	(5.03)	(-1.99)
R-square	0.57	0.40	0.53	0.34	0.29

*Significant at 0.05 significance level; ** significant at 0.01 significance level; *** significance at 0.001 significance level.

The year dummy for 2001 is positively correlated to the share of land allocated to wheat, teff, barley, and lentil, but is only significant for the share of land allocated to wheat and barley. As expected the year dummy for 2002 is negatively related to the land allocated to wheat and lentil. The year 2002 was a bad year with low rainfall. Total land cultivated is positively and significantly correlated to all crops. The share of land allocated to all crop increases if the total land cultivated increases.

5.7 Discussion and Conclusions

This chapter analyzes the relationship between rainfall variability and crop choice. Probit estimation was used for the estimation of the probability of crop choice and the seemingly unrelated regression technique was applied for the estimation of the land allocation model.

It was found that rainfall variability was the most important factor in affecting the probability of crops to be grown. The evidence suggests that choosing the most suited crop mix given the specific rainfall conditions is the most important strategy of farmers in coping with unpredictable rainfall. In conditions of low rainfall, the dominant crop to be chosen for food

[43] The crop specific output price variable is perfectly collinear with the left hand side variable and is therefore

security is teff, barley, and grass pea. The empirical results further suggest that households choose to increase the land allocated to teff, barley, and grass pea by 0.14, 0.39, and 0.05 respectively and reduce the land allocated to wheat by 0.16 when the variability of rain increases by 1 unit, which may help in explaining some of the ex-ante risk management strategies of farmers in the study areas. It was shown that risk reduction is a primary objective of farm households in the study areas.

Family size has a positive effect on the proportion of land allocated to wheat, teff, and barley. These crops require more labor per unit of land. On the contrary family size has a negative effect on the proportion of land allocated to grass pea. The result suggests that less on-farm labor availability increases the proportion of land allocated to grass pea. This result is in line with Woldehanna (2000). He concludes that an increase in family size increases the proportion of land allocated to wheat, teff and barley. These crops are well known for demanding larger amounts of labor in production (Woldehanna, 2000: 169).

It has shown that rainfall variability has a substantial impact on the proportion of land allocated to crops. This suggests that more coordinated effort in the intensification and expansion of irrigation and rainwater harvesting techniques as an ex-ante risk management strategy would have a substantial effect in minimizing the effect of rainfall variability. In so doing farmers would then be able to take the risk of adopting packages of inputs involving new technologies.

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excluded from estimation.

Appendix 5.I Data

Table 5.I Crop specific descriptive statistics (standard deviation in parenthesis)

Variable	Wheat	Teff	Barley	Lentil	Grass pea
Price of seed (Birr/kg))	2.07	2.01	1.66	2.05	0.87
	(1.20)	(0.40)	(0.39)	(0.97)	(2.44)
Price of insecticide	32.40	35.60	23.25		
(Birr/kg))	(10.64)	(13.58)	(0.01)		
Price of fertilizer (Birr/kg)	2.38	2.40	2.45		
	(0.40)	(0.42)	(0.42)		
Labor (hours/hectare)	88.94	181.54	81.52	76.35	70.89
	(50.64)	(117.22)	(411.64)	(62.27)	(37.37)
Share of land allocated	0.34	0.30	0.40	0.18	0.22
(cropland size/total cultivated land) in hectares	(0.16)	(0.17)	(0.19)	(0.08)	(0.13)

Note: the mean and standard deviation of all prices are computed for strictly positive values only.

Table 5.II Descriptive statistics for overall sample[44]

Variable	Number of observations	Mean	Standard deviation	Minimum	Maximum
Number of adults in the household	796	2.69	1.21	0	8
Head age	796	49.79	12.03	22	83
Cultivated land size (hectare)	796	1.79	1.23	0	10.63
Value of livestock (Birr)	659	4162.80	3520.69	150	25200
Coefficient of variation of '*keremet*' rainfall	796	0.87	0.21	0.51	1.15
Year dummy for 2001 (2001=1, 0 otherwise)	796	0.25	0.43	0	1
Year dummy for 2002 (2002=1, 0 otherwise)	796	0.25	0.43	0	1
District dummy (Enderta district=1, 0 otherwise)	796	0.50	0.50	0	1

Note: the mean and standard deviation of value of livestock is computed for strictly positive values only.

[44] The descriptive statistics are computed for those households who farm land. As indicated in the data description chapter of this thesis (Chapter 2) about 11% of the farm households do not cultivate their land.

Appendix 5.II Description of crop choice in the study areas

Depending on the amount, variability and intensity of rainfall farmers grow a variety of crops. Teff, wheat, barley, grass pea, and lentil are the dominant crops grown in the study areas. These crops have different levels of susceptibility to moisture stress, input requirements and storage for home consumption and the potential for cash income. Farmers' crop choice as percentage of the number of farmers and the level of input use per hectare in each of the study areas are presented in Table 5.III and 5.IV respectively. In both of the study areas, barley, which is grown on 39% and 31% of the cultivated land in Enderta and Hintalo-Wajerat, is the most dominant crop. Moreover, about 93% and 85% of farmers in Enderta and Hintalo-Wajerat respectively were choosing barley. It is true that almost all farmers grow barley, because it is believed to be more resistant to drought, and can be dry planted, requires relatively low labor input for production and home consumption and is widely preferred as the staple food. Moreover, barley does have important roles in brewing tella, a locally produced beer for home as well as commercial purposes. Barley grains can be stored for long periods. While wheat is relatively highly susceptible to environmental conditions such as drought and pest attacks and stores poorly, but has a good market price. In Enderta wheat was the second choice after barley but in Hintalo-Wajerat it was the third choice after barley and teff. Teff, indigenous to Ethiopia, forms the staple diet of many Ethiopians and it furnishes the flour to make injera, a sour flat bread type that is highly consumed in urban centers throughout the country. Teff input requirement is high particularly labor and fertilizer and it has high market value (see Table 5.IV). Teff straw from threshed grain is considered to be excellent forage that is superior to straws from other cereals.

Table 5.III – Choice of crop as percentage of number of farmers by district

	Cereals			Pulses	
	Wheat	Teff	Barley	Grass pea	Lentil
Enderta					
1996	86	70	95	35	20
1997	84	78	93	32	37
2001	89	61	91	18	21
2002	86	66	91	23	11
Pooled data over the 4-year period	86	68	93	27	22
Hintalo-Wajerat					
1996	63	57	80	38	2
1997	67	79	91	37	7
2001	87	90	87	50	5
2002	89	92	81	35	2
Pooled data over the 4-year period	76	79	85	40	4

Grass pea, a legume, was cultivated by 27% and 40% of farmers in Enderta and Hintalo-Wajerat respectively. The plant thrives well in areas where other crops would not grow under conditions of poor soil and prolonged drought. It is rich in protein and the seeds are used for home consumption. The entire plant has also been used for nourishing domestic animal feed. Farmers grow grass pea in rotation with cereals. Farmers consider grass pea important in their rotations because as a legume it contributes nitrogen to the soil thus reducing the demand for commercial fertilizer and the depletion of inorganic nitrogen from the soil. Its labor-input requirement per unit is relatively low as compared to other crops.

About 22% and 4% of farmers in Enderta and Hintalo-Wajerat have chosen lentil respectively. The seed has a relatively high content of protein when compared to other legumes and is the most desired crop because of its high average protein content and fast cooking characteristic. Because of this it has a good demand in the towns, where it is used for making wot, which is a type of souse. Just as grass pea lentil also fixes nitrogen and improves the soil fertility. Due to this advantage farmers often grow lentil in rotation with cereals. Furthermore, the rotation also provides for better control of weeds compared with cropping systems containing only cereals.

Table 5.IV—Crop input use per hectare (standard deviation in parenthesis)

	Wheat	Teff	Barley	Grass pea	Lentil
Enderta					
Yield (kg)	154 (83)	141 (98)	217 (112)	122 (70)	78 (92)
Share of land (ha)	0.32 (0.19)	0.16 (0.16)	0.39 (0.22)	0.06 (0.11)	0.04 (0.08)
Labor hour	96 (55)	232 (142)	92 (41)	74 (40)	77 (66)
Local seed (kg)	30 (15)	15 (7)	44 (14)	33 (12)	27 (10)
Improved seed (kg)	6 (14)	0.30 (3)	0.42 (5.75)	0	0
Fertilizer (kg)	12 (14)	47 (59)	10 (15)	0	0
Hintalo-Wajerat					
Yield kg	134 (79)	115 (72)	154 (87)	131 (84)	100 (34)
Share of land in ha	0.24 (0.19)	0.27 (0.21)	0.31 (0.21)	0.09 (0.15)	0.01 (0.04)
Labor hour	81 (44)	139 (67)	71 (39)	68 (37)	68 (45)
Local seed in kg	31 (15)	10 (6)	37 (15)	16 (5)	13 (7)
Improved seed in kg	3 (9)	0.20 (2.28)	0.12 (2.13)	0	0
Fertilizer in kg	3 (8)	11 (17)	4 (10)	0	0

*Note: neither grass pea nor lentil improved seed is available on the market.

In both of the study areas, teff is more labor and fertilizer-demanding crop. In Hintalo-Wajerat, where water deficits are large in much of their cultivated land, the less preferred crop is lentil, as it is a long-day seed to mature. The dominance of barley in both areas may be explained by the fact that it is well adapted to the weather conditions and also is a staple home consumption crop in both areas.

Chapter 6
Off-farm labor supply and the role of rainfall

6.1 Introduction

Rural households in semi-arid areas have to cope with extreme income variability. Household survival depends on the ability to anticipate and to cope with this income variability. Through time, households have developed a range of mechanisms for this. These include use of credit, accumulation of assets, and informal insurance arrangements. For example, Udry (1994) shows to what extent households use credit markets to smooth income shocks in Northern Nigeria. Udry (1995) assessed the use of savings. Fafchamps *et al.* (1998) analyzed the role of livestock holdings, an asset, in a West African context. Dercon and Krishnan (2000) provide evidence on informal risk-sharing arrangements in rural Ethiopia and Hoogeveen (2002) in rural Zimbabwe.

In a resource poor area like Tigray, Northern Ethiopia, the most important risk smoothing mechanism is probably the households' effort to diversify activities or to supply labor off-farm. Here the existence and well-functioning of a labor market is relevant given that labor is the principal asset owned by the poor. For example, using Indian data Kochar (1999) examined household labor supply behavior in response to idiosyncratic crop income shocks. She concludes that in well-functioning rural labor markets households increase their off-farm labor supply in response to crop shocks instead of dissaving or borrowing. Similarly, Rose (2001) found that in India households are more likely to participate in off-farm employment in response to large rainfall variability. Empirical evidence is still lacking on how participation in labor markets is affected by rainfall shocks in a non-dynamic and subsistence agricultural environment like Tigray, Northern Ethiopia, in contrast to the more dynamic rural setting in India. Moreover, examining off-farm labor supply in areas where drought is a common phenomenon helps to identify the opportunities and constraints faced by rural households in the process of stabilizing income and smoothing consumption. Specifically, this chapter addresses the following question: What determines off-farm labor supply and, more specifically what is the role of rainfall and rainfall variability in off-farm labor supply decisions. Answering this question is important in order to gain better insights into the process of how households deal with income variability, and thereby improving policies.

To answer the research question we derive an off-farm labor supply function from a household model that incorporates rainfall and rainfall variability. The function is estimated using panel data collected in Tigray, a non-dynamic and subsistence agricultural environment. A Hausman-Taylor panel data estimator is used for estimation (Hausman and Taylor, 1981; Gardebroek and Oude Lansink, 2003). Estimating the off-farm labor supply function requires accounting for the censored nature of off-farm labor supply. In this paper this is done using a two-step correction (Maddala, 1983: 121-122) in the Hausman-Taylor specification.

The theoretical model is discussed in section 6.2. Section 6.3 presents a description of the dataset. The empirical model and estimation procedure are discussed in section 6.4. Section 6.5 provides a discussion and conclusions.

6.2 Theoretical Model

This section develops a static household model that combines the production, consumption and labor supply decisions of farm households. The model is partly based on Rose (2001).[45] The household model is given by:

$$MaxU = U(C,L) \tag{1}$$

Subject to:

$$P_C C = (P_q Q - P_x X) + wH^O + \overline{Y} \tag{2}$$

$$Q = Q(H^F, X, \overline{A}, E(\theta), \vartheta) \tag{3}$$

$$\overline{T} = L + H^F + H^O \tag{4}$$

$$E(\theta) = \overline{\theta} \tag{5}$$

$$\vartheta = \overline{\vartheta} \tag{6}$$

$$w = w(K, Z) \tag{7}$$

$$L \geq 0, H^F \geq 0, H^O \geq 0, C \geq 0, Q \geq 0, X \geq 0, E(\theta) \geq 0, \vartheta \geq 0, w \geq 0 \tag{8}$$

Where: U utility; C vector of consumption goods; L leisure; P_C vector of prices of consumption goods; P_q price of output; Q quantity of output; P_x vector of prices of variable inputs; X vector of quantities of variable inputs; w off-farm wage; H^0 off-farm employment; $\overline{Y}$ exogenous non-

[45] For details on agricultural household models, see Singh *et al*. (1986), Sadoulet and de Janvry (1995), and Taylor and Adelman (2003). To simplify presentation we omit indices indicating households.

labor income; H^F on-farm labor supply; $\overline{A}$ vector of fixed inputs; $E(\theta)$ expected rainfall (ϑ) actual rainfall; E is expectations operator; $\overline{T}$ total time available; K vector of household characteristics; Z vector of local labor market characteristics.

It is assumed that household preferences can be expressed by a single utility function (equation 1). The household is assumed to maximize utility from consumption and leisure under a budget constraint (equation 2), a technology constraint (equation 3) and time availability constraint (equation 4). The budget constraint (equation 2) states that net household income equals farm income plus off-farm labor income, and other non-labor income, such as remittances. Farm income equals revenue from selling agricultural outputs minus variable costs. Off-farm labor income equals off-farm wage times the amount of labor supplied off-farm. Production (equation 3) is a function of household's on-farm labor supply, variable input use and use of fixed inputs. Moreover, output is assumed to be a function of expected rainfall $E(\theta)$ and actual rainfall (ϑ). Expected rainfall is included because some production decisions (e.g. crop choice) depend on expected rainfall. Of course, total output also depends directly on actual rainfall. Total time available is allocated to on-farm work, off-farm work, and leisure (equation 4). Here it is assumed that household labor is homogenous, so the same type of labor is engaged in leisure, on-farm work and off-farm work. This implies there is one price for labor. Constraints (5) and (6) state that the expected amount of rainfall and actual rainfall are exogenously given at fixed amounts $\overline{\theta}$ and $\overline{\vartheta}$ respectively. The off-farm wage households face (equation 7) is assumed to depend on household characteristics (vector K) and local labor market characteristics (vector Z). Equation (8) gives the non-negativity constraints. Rewriting (4) and substituting (3) and (4) into (2) the budget constraint can be written as:

$$P_C C = P_q Q((\overline{T} - L - H^O), X, \overline{A}, E(\theta), \vartheta) - P_x X + wH^O) + \overline{Y} \qquad (9)$$

The household utility and production function are assumed to be concave, continuous, and twice differentiable, ensuring a utility maximizing solution.

The Lagrangian (G) for the above constrained maximization problem is given by:

$$\begin{aligned} G(C,L) = U(C,L) + \lambda\Big[P_C C - \Big(P_q Q\Big((\overline{Y} - L - H^O), X, \overline{A}, E(\theta), \vartheta\Big) - P_x X + wH^O + \overline{Y}\Big)\Big] + \\ + \gamma\Big(E(\theta) - \overline{\theta}\Big) + \psi(\vartheta - \overline{\vartheta}) \end{aligned} \qquad (10)$$

Where: λ is the Lagrange multiplier associated with the budget constraint, γ and ψ are the Lagrange multipliers associated with the equality constraints of expected rainfall and actual rainfall respectively.

Maximization of this Lagrange with respect to H^O yields the following first-order condition for off-farm labor supply:

$$\frac{\partial G}{\partial H^O} = -P_q \frac{\partial Q}{\partial H^O}\lambda + \lambda w = 0 \;\; \Rightarrow \;\; P_q \frac{\partial Q}{\partial H^O} = w \tag{11}$$

Condition (11) states that off-farm labor is supplied up to the point where the value marginal product of off-farm labor equals the off-farm wage. That is the household allocates its time to off-farm labor supply up to the point where the marginal return from work off-farm is exactly equal to the off-farm wage. Equation (7) shows that this off-farm wage is farm-specific because it depends on household characteristics (e.g. education). This assumption implies that we assume that there is a well-functioning labor market (perfect price elastic demand for labor). If the off-farm wage is lower than the reservation wage (a threshold) then the farm does not supply off-farm labor. In that case the price of labor does not equal the off-farm wage anymore but becomes a shadow wage. We assume the reservation wage is just as the wage determined by household characteristics (vector K) and local labor market characteristics (vector Z). An increase (decrease) of the reservation wage relative to the off-farm wage reduces (increases) the probability of off-farm work participation.

Using the first order condition one can derive the off-farm labor supply function. Off-farm labor supply can be expressed as:

$$\begin{cases} H^O = f(P_q, P_x, \overline{A}, \overline{Y}, E(\theta), \vartheta, K, Z) & \text{if} \quad w > w^r \\ H^O = 0 \quad \text{if} \quad w \le w^r \end{cases} \tag{12}$$

Where: w^r reservation wage.

The reduced form labor supply equation (12) shows that off-farm work is expressed in terms of output prices, variable input prices, amount of fixed inputs, non-labor income, household's expectation of rainfall, amount of actual rainfall, household characteristics and local labor market characteristics (the latter two determining the off-farm wage).

An increase in output prices and a decrease in variable input prices increase farm income and the return on on-farm labor. Given a fixed off-farm wage this implies that more labor will be used on-farm and less labor will be supplied off-farm. Moreover the increase in farm income increases leisure demand which also will lead to a decrease in off-farm labor supply. The effect of the fixed inputs on off-farm labor supply depends on whether on-farm labor and the fixed inputs are substitutes or complements. For example if labor and land are complements then an increase in the amount of land will lead to more on-farm labor, and therefore, to less off-farm labor supply. A marginal increase in the amount of non-labor income received by the household relaxes the budget constraint (see equation 2). If a farm household receives non-labor income, then household members will prefer to work less and enjoy more leisure. In contrast, if there is a decrease in non-labor income received, hours worked are likely to increase. So we expect a negative sign for non-labor income in equation (12).

Expected and actual rainfall in a particular crop year could have three effects on the labor allocation decision. First, marginal increases in the amount of expected or actual rainfall lead to an increase in time allocated to on-farm labor. This implies that farmers allocate more time for land preparation, and planting. Here rainfall and on-farm labor are complements. Second, marginal increases in the expected and actual rainfall lead to a decrease in on-farm labor. This implies that farmers allocate less time to on-farm labor. On-farm labor and rainfall are in that case substitutes. More (less) time allocated to on-farm labor implies less (more) time allocated to off-farm labor. Third, lower expected and actual rainfall would translate into a reduction in farm income that can lead to an increase in off-farm labor supply. In case of a lower expected rainfall this could be interpreted as a precautionary effect.

An off-farm participation model is estimated in section 6.3 in order to determine what factors determine the decision whether or not to work off-farm. This equation is also used to determine the inverse Mills ratio that are included in the off-farm labor supply function, which is the equation of our final interest, to account for the censored nature of off-farm labor supply.

6.3 Empirical Model and Estimation

In this section an off-farm work participation model and off-farm labor supply function are estimated. Given that we have many zero observations, the off-farm labor supply function is estimated as a tobit model. In estimating this tobit model a two-stage approach (Maddala, 1983:

221-222) is used instead of ML in order to take the panel structure of our dataset into account in estimation.

Off-Farm labor Participation Model

The participation model is binary and models the probability of each farm household engaging in off-farm employment. Equation (12) is used to derive the off-farm work participation model. The probability of off-farm work (I=1) participation is specified as:

$$P(I = 1|x) = F(x'\beta) \tag{13}$$

Where: x is a vector of independent variables that are hypothesized to influence households' off-farm participation, F is the cumulative distribution function and β is a vector of coefficients.

The distribution function is assumed to be normal, and is estimated using a pooled probit model.

Explanatory variables included in the participation equation are normalized output prices (prices of less and least rain dependent crop), normalized prices of variable inputs (seed, fertilizer, and an aggregate of pesticides and herbicides), fixed inputs (area of cultivated land, value of large livestock, and value of seep and goat), family size, household head age, education of the household head, rainfall variables (Gurgand index, annual deviation from the 10 year period mean of rainfall, rainfall amounts in March and June), non-labor income and district dummies.

Off-Farm Labor supply Model

The labor supply function is specified as:

$$H_{it}^{*} = X'_{it}\beta + \varepsilon_{it} \tag{14}$$

Where H_{it}^{*} is a latent variable of off-farm hours worked and is observed for values greater than 0 and is censored for values less than or equal to 0; and ε_{it} is a random error. If the disturbance term in (14) is written as $\varepsilon_{it} = \eta_i + u_{it}$, where u_{it} an error term with mean zero and variance σ_u^2, and $E(u_{jt}u_{it}) = 0$ for all $j \neq i$ and $E(u_{it}u_{is}) = 0$ for all $s \neq t$ then the appropriate estimation technique depends on the nature of η_i. η_i is the household specific effect and measures household specific unobserved variables as management skills.

In the presence of a household specific effect (η_i), the fixed effects estimator yields consistent parameter estimates. However, since the fixed effects estimator requires transforming the data into deviations from individual means or first differences to get rid of the fixed effects, time-invariant variables also drop out of the model, even though they could be of interest. If explanatory variables are uncorrelated with the household specific error term a random effects estimation technique can be used. An advantage of the random effects estimator is that it allows estimation of parameters from the time-invariant variables in contrast to the fixed effects estimator. However, the assumption that all explanatory variables are uncorrelated with the household specific effects does not hold in many cases. Hausman and Taylor (1981) proposed a generalized estimation technique that combines the desirable properties from both the fixed effects and random effects estimators. Based on Hausman and Taylor equation (14) is rewritten as:

$$H_{it}^{*} = X'_{1it}\beta_1 + X'_{2it}\beta_2 + Z_{1i}\alpha_1 + Z_{2i}\alpha_2 + \eta_i + \varepsilon_{it} \tag{15}$$

Where X_{1it} are the variables that are time varying and uncorrelated with η_i (time varying exogenous variables); X_{2it} are time varying and correlated with η_i (time varying endogenous variables); Z_{1i} are time invariant and uncorrelated with η_i (time varying exogenous variables); Z_{2i} are time invariant and correlated with η_i (time invariant endogenous variables) and it is assumed that $E[\eta_i] = E[\eta_i | X_{1it}, Z_{1i}] = 0$, $E[\eta_i | X_{2it}, Z_{2i}] \neq 0$, $Var[\eta_i | X_{1it}, Z_{1i}, X_{2it}, Z_{2i}] = \sigma_\eta^2$ and $Var[\eta_i + \varepsilon_{it} | X_{1it}, Z_{1i}, X_{2it}, Z_{2i}] = \sigma_\eta^2 + \sigma_\varepsilon^2$.

The presence of X_{2it} and Z_{2i} would cause estimation bias in case the model would be estimated using a random effects approach. Hausman and Taylor showed how the available model variables can be used to instrument for these variables. The time invariant variables Z_{2i} are instrumented by the individual means $\overline{X}_{1it}$. The time varying variables X_{2it} are instrumented by their deviations from individual means $(X_{2it} - \overline{X}_{2i})$. By definition, Z_{1i} and X'_{1it} are uncorrelated with the household specific error term η_i so that Z_{1i} can serve as its own instrument and $(X_{1it} - \overline{X}_{1i})$ serves as instrument for X_{1it} (Greene, 2003).

In the short-run cultivated land and family size are assumed fixed, and therefore, they are treated as time varying exogenous variables.[46] Rainfall variables are considered exogenous. Prices of insecticides and herbicides and fertilizer are included as exogenous variables, because these prices vary across years but not across households. The Hausman-Taylor estimator is identified if the number of variables that are time varying and uncorrelated with the individual specific effect is greater than the number of variables that are time invariant and correlated with the specific effects. The district dummy, which is a measure of market characteristics, is considered to be a time invariant exogenous variable. Non-labor income received by the household, which is exogenous income that adds to the wealth of the household is treated as a time variant exogenous variable.

Prices of outputs and seed are treated as time-varying endogenous variables. These prices are determined on household level and vary over households and over years. Differences between farms can be interpreted as quality differences (Thijssen, 1992). Household head age and education are also assumed to be correlated with the household specific effects. The former as a time variant endogenous variable while the latter is a dummy and is considered as a time invariant endogenous variable.

Inverse Mills ratio's obtained from the probit off-farm labor participation model are included in equation (15) yielding a tobit specification that is estimated using a two-step approach (Maddala, 1983: 221-222). This accounts for the censored nature of off-farm labor supply.

6.4 Data

The theoretical model described in the previous section is applied to a four year household dataset for Tigray, Northern Ethiopia, covering the years 1996, 1997, 2001 and 2002. The dataset consists of 199 farm households in two districts of southern Tigray. It includes information on household time allocation, off-farm employment, total number of hours worked off farm, and local labor market and household characteristics.

Off-farm working hours and off-farm labor income were recorded by growing season. For estimation purposes off-farm working hours and off-farm labor income were aggregated into yearly data. Because we do not have information about the household specific off-farm wage, it is computed by dividing annual off-farm labor income by annual hours worked off-farm. In the off-

[46] In Ethiopia there is no formal land market. Access to land is based on membership to village communities. Although there is an informal land market in the study area, it is not frequently used by many farmers and it is natural to think of cultivated land as a fixed input in the short run (average cultivated land size in 1996 and 2002

farm participation model the dependent variable is a dummy indicating whether some members of the household participated in the labor market or not. 73.3 percent of the households engage in off-farm employment at some point in the four year sample period.[47] The dependent variable for the off-farm labor supply model is the total number of hours supplied off-farm. The average number of hours worked off-farm is 1530 for 412 observations.

As indicated in the theoretical framework, both expected and actual rainfall can have an effect on households' income and labor allocation decisions. The actual rainfall amount is critical for crop land preparation and crop planting, thus it has an effect on household labor allocation decisions. Therefore the actual monthly rainfall amounts for the short (March) and for the long (June) rain season are included.

Maximizing utility with a production constraint containing expected rainfall is equivalent to utility maximization subject to a production function dependent on the certainty equivalent of rainfall. The certainty equivalent depends on expected rainfall and the variance of rainfall.[48] The more variable rainfall is, the higher the risk involved and the lower the certainty equivalent. From the definition of the certainty equivalent it follows that in the empirical model there has to be an expression for expected rainfall and the variance of rainfall. For expected rainfall, we could use the mean of rainfall in previous years. However, this would imply that this variable would be perfectly correlated with the district dummies. Moreover, since we already included actual rainfall for different years, actual rainfall would also not be a good indicator. Therefore, the certainty equivalent of rainfall is represented only by rainfall variability.[49] Two variables of rainfall variability are constructed. First, rainfall variability is expressed by the Gurgand index (Gurgand, 2003) (for the computation of rainfall variability (Gurgand Index) see Chapter 5 Appendix 6.II). Ex-ante, before the realization of the shock we assume farmers know the distribution of rainfall over time. Second, rainfall variability between years expressed by the annual deviation from the 10 year period 1993-2002 mean of rainfall.[50] This variable measures an ex-post rainfall shock in a particular year.

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was about 1.78 ha and 1.63 ha respectively). Family size is also considered fixed in short run (the average family size in the year 1996 and 2002 was 5.57 and 5.91 members respectively).

[47] The activities in which these 73.3% of the households were engaged include unskilled daily labour (67% of the households), food for work (22% of households involved) and self-employment such as selling fire wood and charcoal, selling cactus etc. (38% of the households). Households were often engaged in more than one type of off-farm employment and therefore the percentages do not add up to 100%.

[48] The certainty equivalent is defined as: $CE(\theta) = E(\theta) - \frac{1}{2} \cdot \gamma \cdot \text{var}(\theta)$, where γ is the Arrow-Pratt measure of absolute risk aversion.

[49] Note that this model set-up corresponds to Rose (2001) who tests the impact of rainfall on labor supply via the average over time and variability of rainfall (coefficient of variation).

[50] To calculate rainfall variability between years we used rainfall data from the two districts for the years 1993 through 2002 (for details of the rainfall data see Chapter 2 of this thesis).

Farmers plant a mix of crops, of which the major ones are barley, wheat, teff, grass pea, and lentil. Based on the amount of rain required the crops are aggregated into: most rain dependent crops (wheat and lentil); less rain dependent (barley and teff) and least rain dependent crop (grass pea). Output prices of these outputs are determined by weighting the prices of the individual crops using the output quantities as weights.[51] Output prices and variable input prices are normalized by the price of the most rain dependent crop (wheat and lentil). Variable inputs are seeds, fertilizer and an aggregate of pesticides and herbicides. Output prices are determined by asking the head of the household what the level of output was and the value of each crop would have been if they had sold total harvest. Seeds of all individual crops are aggregated into one input. Seed price is a weighted average of the prices of individual seeds. The price of individual seeds is determined by asking what the price would have been if farmers would have bought the seeds. Prices of outputs and seed are therefore farm specific. So, they vary over farms and over years. Fertilizer, pesticides and herbicides prices are determined on district level and assumed equal between farms. Pesticides and herbicides are aggregated into one input using quantities as weights.

Fixed inputs are cultivated land, large livestock (which includes value of cattle, horses, mules, camels and donkeys) and small livestock (value of sheep and goats). Including large livestock enables to see if off-farm labor supply and assets are competing strategies to cope with income variability. Household characteristics are family size, which is measured by the number of persons living in the household for at least 9 out of 12 months, age, measured as completed years, and education of the household head. For education an education dummy is used indicating whether the household head is literate or illiterate. A district dummy is also included in the off-farm labor supply function. This dummy captures labor market characteristics of different regions.

Non-labor income (remittances from relatives, food aid from government, gifts or others) is also recorded. The descriptive statistics of the variables used in the analysis are reported in Appendix 6.I.

[51] Alternatively cost and revenue shares could have been used.

6.5 Results

Off-Farm Work Participation Model

Estimation results for the off-farm employment participation model are reported in Table 6.1.[52] The likelihood ratio test outcome of 214.85 indicates that the null hypothesis that all slope coefficients are zero is rejected at the 5 percent significance level.

The Gurgand index is positively related to the off-farm work participation decision. If the Gurgand index increases by one unit, probability of off-farm work increases with 0.09. The annual deviation from the 10 year period mean of rainfall also significantly and positively influences the probability of off-farm employment. The marginal effect indicates that a 1 mm increase in the annual rainfall deviation increases the probability of off-farm work by 0.05. Note that marginal effects in Table 6.1 are calculated at the sample mean and vary over the data range due to the non-linear character of the probit model. These findings indicate that high rainfall variability, as indicator for expected low rainfall, encourages households to engage in off-farm work as an ex-ante income smoothing strategies. Similarly, in the face of low rainfall farm households are more likely to participate in the off-farm employment as an ex-post consumption smoothing strategy. This result is consistent with Rose (2001), who concluded that the probability of household's participation in off-farm employment increases if it expects variable rainfall ex-ante and it experiences a rainfall shock ex-post. In these cases households reduce their income variability through off-farm work.[53]

The rainfall amounts in March and June are significantly and negatively related to the probability of off-farm employment. This indicates that as the rainfall amount in March and June increases by 1 mm the probability of working off-farm decreases by 0.05 and 0.10 respectively. These are the critical months in which on-farm labor is needed for land preparation and sowing. So, in these months on-farm labor increases with good rainfall.

As expected the coefficient of value of large livestock is negatively and significantly related to the probability of off-farm work participation. This suggests that an increase in the value of livestock reduces the probability of off-farm employment. As livestock value is a proxy for wealth, the negative relationship explains that relatively wealthy households are less likely to participate in off-farm work. This finding is consistent with the general belief that livestock is

[52] Marginal effects are calculated as the derivatives of the cumulative normal distribution at the mean of the explanatory variables; for dummies the marginal effect is expressed as the discrete change from 0 to 1.
[53] Here farm households are motivated to participate in the off-farm labor market by a 'push' factor—farm income variability resulting from insufficient rainfall for crops to grow.

used as an income and consumption smoothing strategy in most developing countries.[54] Another interpretation could be that since large livestock is used in crop production an increase in large livestock leads to an increase in the marginal productivity of farm labor. This leads, given a fixed external wage, to a decrease in off-farm employment. Similarly, the amount of cultivated land negatively influences the probability of off-farm employment. The marginal effect suggests that a 1 hectare increase in the size of the farm reduces the probability of off-farm work by 0.02.

The coefficient for household head age indicates that households with older heads are less likely to participate in off-farm employment. The age of household head also proxies the stage in the family life cycle. Younger household heads have both the ability and the need (to take care of dependent family members in the household) to work off-farm. Contrary to expectations education of the household head had no influence on the probability of off-farm work participation. This is possibly because of insufficient variability between households.[55]

The probability of off-farm employment participation positively increases with family size. This suggests that larger households have a tighter budget constraint (insufficient farm income) thus a higher need for additional income. Another reason could be that a large family size results in a low on-farm marginal productivity of labor. An increase with 1 extra member increases the probability of off-farm employment with 0.06. This result is consistent with Woldehanna (2000) and Matshe and Young (2004).

Finally, normalized output and variable input prices do not have a statistically significant relation with the probability of off-farm work. The normalized price of the less rain dependent crop has the expected sign. As the price of the less rain dependent crop increases by 1 Birr the probability of off-farm work decreases with 0.04, but not significantly. Contrary to expectations, the price of the least rain dependent crop is positively related to the probability of off-farm work. The price of seed is negatively related to the probability of off-farm employment. A high seed price is to be expected if farms have the expectation that growing crops is profitable. This reduces off-farm labor supply. This is consistent with the situation of the farmers in the study areas where farmers usually save their own seed for sowing. Price of insecticides and herbicides is positively related to the probability of participation in off-farm employment. Herbicides and insecticides represent a labor saving technology and have a positive effect on the decisions to work off-farm. However the coefficient is not significantly different from zero.

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[54] Fafchamps *et al*. (1998) show for West Africa that during drought years livestock sales compensated for 15 to 30 percent of the income fluctuations.

[55] This is an unexpected result because most of the literature, for example Matshe and Young (2004), report a positive and significant relationship between the probability of off-farm employment and household head education.

In sum, the general picture that emerges is that off-farm employment is an important income stabilization strategy for rural farm households in Tigray that maintain traditional production systems primarily oriented toward self-consumption.

Table 6.1 Estimation results and marginal effects of the probability of household off-farm work participation[56]

Variable	Coefficient	z-value	Marginal effect
Intercept	-3.0894*	-5.41	
Price of less rain dependent crop	-0.1078	-0.55	-0.04
Price of least rain dependent crop	0.0436	0.33	0.02
Seed price	-0.0680	-0.43	-0.03
Insecticide & herbicide price	0.0036	0.79	0.00
Fertilizer price	-0.1438	-1.71	-0.06
Rainfall variability: Gurgand index	0.2160*	9.61	0.09
Annual deviation from the 10 year period mean of rainfall	0.1201*	9.21	0.05
Rainfall in March	-0.1281*	-8.53	-0.05
Rainfall in June	-0.2594*	-9.65	-0.10
Non-labor income	-0.0000	-0.36	-0.00
Value of large livestock	-0.0001*	-4.08	-0.00
Value of sheep & goat	0.0001	0.17	0.00
Cultivated land	-0.0458*	-2.56	-0.02
Family size	0.1412*	5.02	0.06
Head age	-0.0180*	-3.81	-0.01
Dummy head education	-0.2091	-1.85	-0.08
Dummy district	12.4025*	9.89	1.00
Log likelihood	-383.25		
LR chi2(17)	214.85*		
Pseudo R2	0.22		
Number of observations	708		

*significant at 0.05

Labor supply model

The labor supply model was estimated using the procedure described in the previous section. A standard Hausman (1978) test comparing random effects and fixed effects estimates was performed to determine whether the random-effects estimator would have been appropriate. The test statistic of 28.01 is larger than the critical value $\chi^2_{15;0.95} = 25.00$. So, it is concluded that there is correlation between at least one of the included variables and the household specific effect, so that the random-effects estimator would give biased estimates. An additional Hausman test is conducted to test the Hausman-Taylor model specification against a fixed-effects model.

[56] Since the left hand side variable is binary the farm-specific wage variable would be perfectly collinear, and is therefore excluded from estimation.

The test statistic of 7.20 is less than the critical value of 25.00, indicating that the chosen specification for the Hausman-Taylor model gives unbiased estimates.

Estimation results for the labor supply model are presented in Table 6.2. As expected, rainfall and rainfall variability (Gurgand Index) relate positively, and significantly, to the number of hours worked. Households increase off-farm labor supply in response to an increase in the Gurgand index and the annual deviation from the 10 year period mean of rainfall.[57] In response to a 1% increase in the Gurgand index the number of hours worked off-farm increases by 9.32. Similarly the number of hours supplied off-farm increases by 0.98 if the annual deviation from the 10 year period mean of rainfall increases by 1%. Rainfall amounts in March and June are negatively correlated with off-farm labor supply. As expected, rainfall amounts in March and June and on-farm labor are complements. During the growing season of the cropping year, on-farm labor productivity increases, and households are encouraged to supply more labor on-farm. A 1% increase in rainfall in June reduces the off-farm employment by 6.55. June is the month, where most of crop planting takes place.

Table 6.2 Estimation results and elasticities of household's off-farm labor supply

Variable	Coefficient	z-value	Elasticity's at mean value
Intercept	-1229.23	-1.05	
Time Variant exogenous variables			
Insecticide & herbicide price	6.17*	2.61	0.02
Fertilizer price	-248.01*	-3.38	-0.21
Rainfall variability: Gurgand index	144.41*	2.73	9.32
Annual deviation from the 10 year period mean of rainfall	84.87*	2.83	0.98
Rainfall in March	-98.11*	-3.09	-3.06
Rainfall in June	-154.90*	-2.45	-6.55
Non-labor income	-0.11	-1.29	-0.02
Value of large livestock	-0.07*	-2.24	-0.38
Value of sheep & goat	-0.05	-0.15	-0.00
Cultivated land	-25.55	-1.33	-0.27
Family size	93.43	1.91	0.76
Inverse Mills ratio	386.11	0.88	
Time Variant endogenous variables			
Price of less rain dependent crop	-227.95	-1.61	-0.21
Price of least rain dependent crop	25.71	0.25	0.01
Seed price	102.55	0.92	0.12
Head age	-32.51*	-3.64	-2.17
Time Invariant endogenous variable			
Dummy head education	765.33	1.51	0.41
Time Invariant exogenous variable			
Dummy district	8438.50*	2.76	5.43
Wald chi2(18)	168.50*		
Number of observation	708		

*significant at 0.05. The inverse Mills ratio is obtained from the equation on the probability of working off-farm and is used as an explanatory variable in the off-farm labor supply function (equation 15)

The coefficients of the values of large livestock and small livestock have a negative sign. The coefficient for large livestock is statistically significant, while for small livestock it is not significant. This shows that if the value of large livestock increases with 1% the number of hours worked reduces with 0.38. This confirms that large livestock, an asset, is an alternative for off-farm labor supply as a way to cope with income variability. Moreover, given that large livestock is used in crop production, a large livestock increases the marginal productivity of on-farm labor reducing the supply of off-farm labor. The sign of the coefficient representing cultivated land is negative suggesting that as farm size increases the number of hours supplied to off-farm work declines. However, the coefficient is not statistically significant. Non-labor income has a negative effect on off-farm labor supply. However, the coefficient is not statistically significant. Off-farm hours supplied increase if family size increases (statistically significant). The elasticity shows that as the number of family size increases by 1% off-farm hours supplied increase by 0.76.

None of the normalized output prices have a significant effect on off-farm labor supply. The sign of the price of the less rain dependent crop has the expected negative sign. This implies that if the price of the less rain dependent crop increases off-farm labor supply decreases. Normalized prices of seed and insecticides and herbicides have the expected sign. The price of insecticides and herbicides has a significant and positive effect on off-farm labor supply. This suggests insecticides and herbicides and off-farm labor supply are alternatives to deal with income variability. The coefficient for the price of seed is not significantly different from zero. Households reduce the number of hours supplied to off-farm work in response to a fertilizer price increase. This indicates fertilizer is a substitute for labor.

In the face of rainfall variability and low rainfall amounts households supply more hours to off-farm work. This is more likely to be the case when the household is poor (has no livestock). Off-farm labor supply is used as an income smoothing and mitigation mechanism.

6.6 Discussion and conclusions

This chapter addresses the following question: What determines off-farm labor supply decisions and, more specifically, what is the role of rainfall and rainfall variability therein. To answer this questions the discrete off-farm work decision and labor supply function were modeled for a sample of Tigray farm households observed in 1996-1997 and 2001-2002. A probit model was used to estimate the off-farm work participation model and a Hausman-Taylor panel data estimator was applied in estimation of the labor supply model.

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[57] Kochar (1999) also finds that households increase their off-farm labor supply in response to an income shock.

Results confirm that rainfall variability and low rainfall amounts increase the probability of off-farm labor supply. Off-farm labor supply can be therefore being seen as an income smoothing strategy followed in response to rainfall variability. These finding are consistent with Rose (2001) who confirmed the existence of an ex-ante and ex-post labor supply responses to rainfall risk. Wealth, in the form of a large livestock, has a negative effect on off-farm work participation and hours worked. This confirms that large livestock is an alternative for off-farm labor supply to cope with income variability. The price of insecticides and herbicides has a significant and positive effect on off-farm labor supply. So, also insecticides and herbicides are a possible alternative for off-farm labor supply to deal with income variability. As expected also family size has a positive effect on off-farm labor supply. Output prices and farm size did not have a significant effect on off-farm employment.

The analysis in this chapter is subject to some qualifications. First, this study has only addressed off-farm labor participation and labor supply responses in reaction to rainfall and rainfall variability. However, there are other sources of risk then risk related to rainfall, e.g. market price risk. Second, here we looked at off-farm labor isolated from other decisions taken on the farm. Especially, we ignored gender issues. Men and women tend to invest in different skills and thus could face different labor market opportunities. Woldehanna (2000) makes such a distinction but he does not focus on the role of rainfall and rainfall variability.

We conclude that off-farm labor supply is important in mitigating and coping with income variability related to rainfall variability. This shows the importance of economic development outside and inside agriculture creating job opportunities.

Appendix 6.I Data

Table 6.I Descriptive Statistics[58]

Definition	Number of Observations	Mean	Standard Deviation	Minimum	Maximum
Dependent Variables					
Off-farm participation (=1 if household members engage in off-farm work)	708	0.51	0.50	0	1
Off-farm number of hours supplied	412	1530.23	1303.31	24	9920
Farm Characteristics					
Cultivated land in hectares	708	2.01	1.13	0.25	10.63
Price of less rain dependent crop Eth Birr/kg	560	0.86	0.23	0.08	2.39
Price of least rain dependent crop Eth Birr	195	0.82	0.43	0.04	5.31
Seed price Eth Birr	573	1.04	0.37	0.11	4.82
Insecticide and herbicide price Eth Birr	26	53.35	69.83	0.67	277.78
Fertilizer Price Eth Birr	322	1.41	0.45	0.15	4.81
Value of large livestock Eth Birr	659	4162.80	3520.69	150	25200
Value of sheep & goat Eth Birr	63	323.57	340.28	50	1600
Rainfall					
Gurgand index	708	48.29	17.09	14.20	70.78
Annual deviation from the 10 year period mean of rainfall[59]	708	-8.60	17.10	-37.38	26.62
Rainfall amount in March	708	23.37	14.92	0	48.20
Rainfall amount in June	708	31.65	11.463	11	52.20
Other household income					
Non-labor income Eth Birr	708	132.26	480.94	0	6250
Household head characteristics					
Head age	708	49.93	11.75	22	80
Education household head (=1 if head is literate, 0 if illiterate)	708	0.40	0.49	0	1
Household characteristics					
Family size	708	6.08	2.03	1	11
Market characteristics					
District dummy variable (=1 if Enderta district and 0 if Hintalo-Wajerat district)					

[58] The descriptive statistics for number of hours supplied are computed for those who work off-farm that is 412 farm households. The descriptive statistics for crop prices are computed for those who produced the crop. Similarly, price of inputs (seed, insecticide and herbicide, and fertilizer) are computed for those who used the inputs. Value of large livestock and small livestock is computed for those who owned livestock.

[59] The mean is not zero because it is calculated for the four years we have panel data. So in these years there was less rainfall than the mean of the ten year period.

Appendix 6.II Gurgand index

The restrictive assumption here is that prior to the realization of rainfall farm households know the distribution of rainfall over time. Households' expectation of rainfall variability can then be represented by its variance. Variability of rainfall is computed using the Gurgand index (2003). That is, $\sigma^2 = \sqrt{1/12\sum_{m=1}^{12}(m_{dmt} - \overline{m}_{dm})^2}$ where d, t, and m denote district, a given year and a given month respectively and σ^2 is Gurgand index. m_{dmt} measures the monthly rainfall amount in district d during the year t and in a specific month m. And $\overline{m}_{dm}$ measures the average rainfall amount in district d and month m over the period 1993 to 2002.

The Gurgand index measures how typical rainfall has been in a given year. For every calendar month, the average precipitation over the period 1993-2002 is taken as "normal" and deviation from this value for a given year is exceptional rainfall.

Chapter 7
Fertilizer Adoption, Consumption, and Rainfall

7.1 Introduction

It has long been established that the primary means of "getting agriculture moving" and raising rural farm income in developing countries is through the adoption of new production technologies, especially chemical fertilizer and high-yielding varieties of seed (Hayami and Ruttan, 1985).[60] Despite significant yield increases obtained in experimental stations and on farm trials, farmer's use of fertilizer in the highland areas of Ethiopia remains low (Belete *et al*., 1992). Among the major impediments to the adoption of fertilizer has been the risk-aversion behavior of farmers (Antle, 1987; Binswanger, 1980, 1981; Feder, 1980). In the absence of insurance and credit markets, risk-averse farmers have developed various ways to try to smooth consumption both ex-ante and ex-post. Rosenzweig and Binswanger (1993) found that farmers in semi-arid India select portfolios of assets that are less sensitive to rainfall variations and thus less profitable. Similarly Dercon (1996) showed that farmers with limited option to smooth consumption ex-post were found to grow safer crops but with lower returns. Moreover farmers also rely on informal risk sharing arrangements and savings to smooth consumption ex-post but such strategies are seldom able to cope fully with consumption shocks. For example, Townsend (1994) and Paxson (1992) have examined the variability of consumption ex-post of informal risk-coping mechanisms. They found that, in the presence of shocks households are partly able to smooth consumption.

Risk aversion and limited capacity of farm households to smooth consumption ex-post have been argued to play an important role in inhibiting the adoption of new technologies (Feder *et al*., 1985). Moreover, the risk-increasing role of new technologies exacerbates the effect of risk aversion on production choices. This is apparent in Tigray, where extreme rainfall variability tends to be severe in its impact on crop yields. In dealing with income variability, the first priority is avoiding that consumption falls below the survival threshold. In doing so, farmers choose traditional inputs, such as organic fertilizers and traditional seeds, over new technology inputs (such as chemical fertilizer and improved seeds). As a result ex-post consumption will respond to shocks in a way that depends on the ex-ante production choice. Any market mechanism that

[60] Adoption of new agricultural technologies is the main vehicle for reducing poverty and growth in the agricultural sector. The latter plays a major role in the overall growth of the Ethiopian economy and in connecting the poor to growth. Higher productivity in agriculture provides food, labor, and even savings stimulating the process of urbanization and industrialization. Thus, a dynamic agriculture raises labor productivity in the rural economy of Ethiopia, pulls up wages, and gradually eliminates the worst dimensions of absolute poverty ((MOFED, 2002).

allows farmers to smooth consumption ex-post will raise the use of new technology inputs and thereby increase farmer's income.

The decision to adopt new technologies (chemical fertilizer) is extensively studied in Ethiopia. For example Asfaw and Admassie (2004) explained the role of education on the adoption of chemical fertilizers. Demeke *et al*. (1997) analyzed the implication of grain market improvements in promoting fertilizer use. Belete *et al*. (1992) looked at the impact of fertilizer use on production and cash income of small-scale farmers in the highlands of Ethiopia. However, very little is known about the effect of ex-post consumption smoothing strategies on the ex-ante utilization of chemical fertilizers. Recently, using Ethiopian Rural Household Survey data on five major regions, Dercon and Christiaensen (2005) analyzed the impact of new technology adoption on consumption, and poverty. However, the impact of ex-post consumption smoothing strategies on the adoption of new technologies under extreme rainfall variability has not been thoroughly investigated in non-dynamic and subsistence agricultural environments, where production is primarily for subsistence consumption. The general objective of this chapter is thus, to examine the impact of rainfall on the adoption of chemical fertilizer. Specifically the following questions will be addressed: (1) Does rainfall has a significant effect on the adoption of chemical fertilizer? (2) To what extent do fertilizer adoptions affect consumption?

An inter-temporal consumption model was used to answer the research questions. The method was applied to a four-year balanced panel data collected in Tigray, Northern Ethiopia.

Section 7.2 discusses a consumption model to reflect the peculiarities of a typical household in developing countries. Section 7.2 briefly describes the data set. Section 7.3 develops the empirical model and estimation methods for analyzing the research questions. Results are presented and discussed in section 7.4. Conclusions are presented in Section 7.5, which also draws some policy implications.

7.2 Consumption Smoothing and ex-ante Fertilizer Adoption: a theoretical model[61]

Household Optimization Model

Assume $U_t(C_\tau)$ is a continuous differentiable utility function of a household, where C_τ is household consumption of goods and services at time period τ. Since the consumption choice is

[61] This section draws heavily from the work of Dercon and Christiaensen (2005). To simplify presentation we omit indices indicating households.

concerned with resource allocation over time, consider a household maximizing the expected lifetime utility in time zero. The utility $U_t(C_\tau)$ is assumed to be time and space separable.[62]

$$E\left[\sum_{\tau=t}^{T}(1+\rho)^{t-\tau}U_t(C_\tau)\middle|I_t\right] \tag{1}$$

Where T is the life span of the household[63], $E(\cdot|I_t)$ is an expectation conditional on information available at time *t*, I_t is the information set at t, and ρ is the rate of time preference. The household is assumed to maximize the present discounted value of expected utility, conditional on information available at time *t*. The evolution of household assets governs the budget constraint within which intertemporal utility is maximized:

$$A_{t+1} = (1+r_t)(A_t + Y_t - C_t) \tag{2}$$

Where A_t is household's wealth at *t*, Y_t is labor income, which is stochastic but known at t, and r_t is the real interest rate at *t* and C_t is consumption expenditures at t.

Dynamic optimization is used to solve the problem implied by (1) and (2). The first order optimization leads to the standard Euler equation:

$$U'(C_t) = (1+\rho)^{-1}(1+r_t)E_t\left[U'(C_{t+1})\right] \tag{3}$$

Equation (3) implies that the marginal utility of current consumption is equal to the discounted expected marginal utility of future consumption (Deaton, 1992b). The parameter r and ρ control the rate at which expected marginal utility tomorrow is discounted relative to marginal utility today.

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[62] Utility is assumed to be time separable. That is the utility that consumption yields today does not depend on the levels of consumption in other periods, past or future (Romer, 2001).

[63] T can be assumed to be infinity (∞), as there are strong ties among generations in Ethiopia.

Consumption Smoothing Model: The Permanent Income or Life-Cycle Model[64]

The permanent income and the life-cycle model are special case of equation (3). If we assume that the instantaneous utility function is quadratic, separable across periods, and that the rate of time preference (ρ) is constant and equal to the interest rate, so that equation (3) becomes:

$$U'(C_t) = U'(E_t(C_{t+1})) \tag{4}$$

Equation (4) implies that the expected marginal utility of consumption is the same as the marginal utility of current consumption. That is, the optimal path of consumption is such that consumption is expected to be constant over the lifetime of the household (Blanchard and Fischer, 1989: 286).

If the permanent income or life-cycle hypothesis that follows from equation (4) is valid, then consumption only depends on lifetime resources (such as household's age profile) or on permanent income (which is defined as the annuity value of the sum of current assets and the discounted present value of expected future earnings). According to the permanent income hypothesis, transitory or unexpected shocks to permanent income will have little effect on household consumption. In response to such a transitory shock the household will accumulate assets, to be depleted later when a negative shock arises or households are able to borrow at current interest rates. Only permanent income shocks, which cause a large change in the household's expectation of future income, will have an effect on consumption.[65]

However, in developing countries, formal credit and insurance markets are imperfect or absent, leaving households to smoothing consumption by undertaking more conservative production systems and diversification of portfolio of activities (see Chapter 5 and Chapter 6 of this thesis).[66]

To test whether ex-ante fertilizer adoption is affected by the limited ex-post consumption smoothing ability of households, we use the permanent income or life-cycle model. Here we need to distinguish permanent income and transitory income. Using the methodology formulated by Paxson (1992)[67], we use rainfall variability as a transitory component of income (Y_t^T).[68] The part

[64] The permanent income hypothesis and life-cycle model are the standard tools economists use for modeling life-cycle choices (such as consumption).
[65] In this study permanent income is defined as expected income for year *t* conditional on the resources available and information of the household at the beginning of the period.
[66] Households whose livelihood and employment depend on mainly rain-fed agriculture rainfall-related shocks could result in harvest failure and as a consequence ex-post consumption could fluctuate. Under such a high risky environment, households who expect high rainfall variability ahead may use more conservative production technologies to maintain smooth consumption ex-post. For example in Tigray, where most of the poor reside in rural areas and rely on agricultural activities for their livelihoods, rainfall variability can have a major impact on their agricultural production decisions.
[67] Paxson (1992: 15) in her study on Thai rice farmers, identifies that the part of each household's income that is explained by shocks to regional rainfall serves as an explicit measure of transitory income.

of household income explained by households' permanent variables (such as number of household members of different sex and in different age categories) at time *t* serves as an explicit measure of permanent income (Y_t^P).Rewriting equation (4) gives

$$U'(C_t, Y_t^P, Y_t^T) = U'(E_t(C_{t+1}, Y_{t+1}^P, Y_{t+1}^T)) \tag{5}$$

One of the testable implications of Equation (5) is that only shocks to permanent income would change the optimal consumption plan, and transitory shocks are smoothed (Paxson, 1992; Deaton, 1992). It is hypothesized that adoption of risky inputs ex-ante results in variability of net farm return, which might result in variability of ex-post consumption—if the household is budget constrained.

Using the first order condition of equation (5), ex-post consumption function is derived as:

$$C_t = f(X_t^P, X_t^T) \tag{6}$$

Where X_t^P is a vector of variables that determine the household's permanent income (life-cycle), which is proxied by a vector of household members in different age / sex categories, and household livestock wealth variables,[69] X_t^T is a vector of variables that determine the transitory component of household income (which is proxied by village level rainfall variability). Rainfall variability also enters into the consumption function (equation 6) through interactions with the household wealth level measured by the value of livestock. This interaction term measures whether the effect of rainfall variability on consumption varies with household's wealth.

Equation (6) gives the reduced-form consumption function and shows that consumption at period *t* is a function of variables that affect the permanent income and transitory income component of the household.

Fertilizer Adoption Model

Considering the economic diversification of farm households in developing countries, labor income Y_t in equation (2) can be disaggregated into off-farm income $\overline{Y}_t$ and farm gross revenue R_t minus variable costs (farm income). Then the budget constraint (2) becomes

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[68] Crop income shocks is proxied by rainfall variability (Gurgand index). It is plausible to use rainfall variability to proxy crop income shocks because in the study area crop income risk is very much driven by rainfall variability.

$$A_{t+1} = (1+r)(A_t + \overline{Y}_t + R_t(X_t^F(E_t(\theta_t)), X_t^O, \theta_t) - P_t^O X_t^O - P_t^F X_t^F - C_t) \qquad (2')$$

Where: X_t^O and X_t^F are vector of quantities of other variable inputs and fertilizer respectively, P_t^O and P_t^F vector of prices of other variable inputs and fertilizer respectively. The budget constraint accordingly reflects possibilities of consumption versus buying risky inputs as fertilizer. Moreover, fertilizer input decision is a function of expectation of rainfall at time t (θ_t).

The budget constraint (equation 2') at the beginning of period $t+1$ is the sum of initial wealth in the previous period (A_t) plus off-farm income (off-farm income is the sum of wage and self-employment income) and gross farm revenue minus variable input costs and consumption expenditure in period t. Gross farm income is random and is not known at the beginning of period t, when input decisions are made. However, it depends on the expectations on rainfall conditions θ_t and on risky input use X_t^F at period t. All input decisions are made at the beginning of period t, while it is assumed that consumption decisions are made after the realization of farm income.

Let the expected net returns to farm production be denoted by $E_t(y_t) = R_t(X_t, \theta_t) - P_t^O X_t^O - P_t^F X_t^F$. Assume that the net return to production is concave, continuous, and twice differentiable, then $\partial E_t(y_t)/\partial X_t^F > 0$, and $\partial^2 E_t(y_t)/\partial X_t^{F2} < 0$.[70] If the expectation of rainfall is positive $E_t(\theta_t) > 0$, then marginal product of fertilizer is also positive i.e., $\partial y_t/\partial X_t^F > 0$ and $\partial y_t/\partial \theta_t > 0$. In contrary if $E_t(\theta_t) < 0$ then $\partial y_t/\partial X_t^F < 0$. In good rainfall years, choosing the risky input (fertilizer) increases expected output and net returns to production, while in bad rainfall years, choosing the risky input results in losses.

Let the seasonal budget constraint be denoted by $A_t - P_t^O X_t^O - P_t^F X_t^F > 0$. The first order dynamic optimization yields the optimal level of ex-ante fertilizer input use:

$$X_t'^F(C_t, Y_t^P, Y_t^T) = E_t\left[U'(C_{t+1}, Y_{t+1}^P, Y_{t+1}^T)\frac{\partial E_t(y_t(\theta_t))}{\partial X_t^F}\right] - \lambda P_t^F = 0 \qquad (7)$$

Where λ the Lagrange multiplier associated with the seasonal budget constraint.

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[69] Permanent income is defined over a short time horizon, as expected income for year *t+1* is conditional on the resources and information of the household at the beginning of the period *t*.

Condition (7) states that if the seasonal credit constraint is not binding ($\lambda = 0$), then the value marginal product of fertilizer is equal to its price. If the seasonal budget constraint is binding, lower fertilizer levels are obtained (Dercon and Christiaensen, 2005). An increase (decrease) in household's expectation of ex-post consumption (i.e. in period *t+1*) increases (reduces) the probability of fertilizer adoption. That is, if households are confronted with a budget constraint to smooth consumption ex-post, then ex-ante fertilizer adoption is affected.

Since wealth at the beginning of period $t+1$ is a function of farm income, which is a function of the exogenous variable rainfall, a marginal increase in the expected amount or actual rainfall could have a direct effect on farm income. A marginal increase in the amount of expected rainfall leads to a marginal increase in farm income, which could have also an indirect effect on consumption. On the other hand a marginal increase in return to the risky input relaxes the inter-temporal budget constraint, which could lead to an increase in consumption at the beginning of period *t+1*. It is hypothesized that the decision to use the risky input is based on the expectation of consumption fluctuations. Because the more the risky input is adopted, the riskier the net returns to production which could result in consumption fluctuations.

The fertilizer adoption model can be derived from the first order condition (equation 7).

$$\begin{cases} X_t^F = f(C_t, X_t^P, X_t^T) & \text{if} \quad E_t(\Delta C_{t+1}) > 0 \\ X_t^F = 0 & \text{if} \quad \mathrm{E}_t(\Delta C_{t+1}) < 0 \end{cases} \tag{8}$$

Where ΔC_{t+1} is the change of consumption from period *t* (ex-ante consumption) and period *t+1* (ex-post consumption). All other variables are as defined before. The reduced form of the fertilizer adoption model (equation 8) is a function of variables that determine the household's permanent income (household members in different age / sex categories, livestock wealth, and cultivated land size[71]), consumption, and vector of variables that determine the transitory component of household income.

[70] It seems reasonable to consider that the marginal return to fertilizer contributes positively to expected net returns to production, while the second derivative corresponds to the usual concavity of net returns.

[71] Cultivated land size is usually taken as a measure of wealth and reflects the social status and possibly the ability of farmers to cope with rainfall-induced risk. However, in Ethiopia land is state owned. Farmers only have user rights and have the right to lease. Because of the absence of formal land markets land cannot be used for household ex-post consumption smoothing strategies.

7.3 Empirical Model and Estimation

To test the model developed in section 7.2, empirical models of consumption smoothing and fertilizer adoption are specified in this section.

Consumption Model

The household consumption function in period *t* is specified as:

$$C_{it} = X'_{it}\beta + \varepsilon_{it} \qquad i = 1,..,N \qquad t = 1,..,4 \tag{9}$$

Where subscript *i* denotes household i, subscript *t* denotes year t, C_{it} is consumption per adult equivalent for household *i* in year *t,* X_{it} explanatory variables for consumption per adult equivalent of household i in year t, β is a vector of coefficients, and ε_{it} error term.

If the error term in equation (8) is written as $\varepsilon_{it} = \alpha_i + \eta_{it}$, where η_{it} is a common stochastic error term, with mean zero and variance σ^2_η. η_{it} is assumed to be uncorrelated with X_{it}, and assumed to vary across households,($E(\eta_{it}\eta_{jt}) = 0$ for all $i \neq j$) and across time ($E(\eta_{it}\eta_{is}) = 0$ for all $s \neq t$). Then the appropriate estimation technique depends on the nature of α_i, which is the unobserved household specific effect, assumed to vary across households but being constant over time. If we assume that α_i is uncorrelated to X_{it}, and α_i is a random variable which represents an additional source of errors in the regression, then a random effect estimator is most appropriate. If α_i is correlated with X_{it} the fixed effects estimator yields unbiased parameter estimates.

The explanatory variables included in the consumption equation are household size by age and sex category, rainfall variability, livestock value and an interaction term of rainfall variability with livestock value.

Fertilizer Adoption Model

The decision of households to adopt fertilizer is assumed to be governed by the expectation of ex-post consumption smoothing abilities of the household. Equation (8) is used to derive the fertilizer adoption model and be specified as:

$$P(I_{it} = 1|x_{it}) = F(\beta x'_{it} + v_i + u_{it}) \tag{10}$$

Where I_{it} is an indicator dummy for fertilizer adoption $(I_{it} = 1)$, x_{it} explanatory variables for household i in year t that are hypothesized to influence households' fertilizer adoption decision, F is the cumulative distribution function, β is a vector of coefficients, v_i is the unobserved household specific effect, and u_{it} error term.

The dependent variable in equation (9) is a binary choice variable. If we assume $F(\cdot)$ to be normally distributed and if explanatory variables are uncorrelated with the household specific effect (v_i) a probit random effects estimator can be used. However, the assumption that all explanatory variables are uncorrelated with the household specific effects is unlikely to be met in this data set. If we assume the household specific effect (v_i) is correlated with explanatory variables then the conditional fixed effects estimator yields unbiased parameter estimates (Greene, 2003). The fertilizer adoption model (equation 9), is therefore estimated using the conditional fixed effects estimator. The Hausman (1978) specification test was used to test whether there is a household specific effect or not. If there would be no household specific effect, the model could be estimated using the logit estimator, i.e. by unconditional maximum likelihood.

Explanatory variables included in the fertilizer adoption equation are household size by age and sex category, rainfall variability, livestock value, cultivated land size, and variability of consumption.

Fertilizer Application Rate

The model for fertilizer application rates can be derived from equation (10). The model for estimating fertilizer application rates is written as:

$$X_t^F = \begin{cases} X_t^{F*} = x'\beta + \varepsilon & \text{if} \quad H_t^{F*} > 0 \\ \quad\;\; = 0 & \text{if} \quad \mathrm{H}_t^{F*} \leq 0 \end{cases} \tag{11}$$

Where X_t^{F*} is a latent variable that is observed for values greater than 0 and is censored for values less than or equal to 0, x is a vector of variables believed to influence the amount of fertilizer application per hectare, β is a vector of coefficients to be estimated, and ε is a normally distributed stochastic error term with mean zero and variance σ_{ε}^{2}.

Since there are many zero observations for fertilizer use in the sample, a standard regression analysis can be misleading. We test if there is a sample selection bias for fertilizer application.

7.4 Data

The data on which our analysis is based come from a 4-year household survey conducted in two districts of Tigray northern Ethiopia, covering the years 1996, 1997, 2001 and 2002. The dataset consists of a panel of 199 randomly selected households in the districts Enderta and Hintalo-Wajerat. Among others the data contains information on socio-demographic characteristics, incomes, food consumption expenditure, and annual fertilizer utilization.

The dependent variable in the fertilizer adoption model is a dummy indicating whether the household used fertilizer or not during the survey period. 46 percent of the households used fertilizer as an input to the major crops (wheat, teff, and barley). In the fertilizer application model the dependent variable is the amount of fertilizer (kilogram) used per hectare by the households in the sample. In the consumption model the dependent variable is the value of food consumed measured in consumption per adult equivalent. Since consumption data are available only at the household level, correcting for household size and composition is needed.[72] Total food consumption per adult equivalent was computed as the sum of values of all food items consumed (including purchased meals) divided by total adult equivalents as a measure of household size. Own production, gifts or wage in kind consumption were valued using village level prices that were collected at the time of the survey.[73][74]

The independent variables used in both of the models are variables that are hypothesized to determine the permanent income (life-cycle) hypothesis. The permanent income or life-cycle factors in the consumption and fertilizer adoption models consist of variables that measure the

[72] Since food consumption varies by age and sex, we computed adult equivalence scales using World Health Organization conversion codes (the equivalence scales used are presented in Appendix 7.I). Adult equivalence scales give the food consumption requirements of different age groups in the household as a proportion of those of an adult male.
[73] Three questions were offered to the farm household in collecting the information on food consumption. These were: did you consume purchased food, did you consume from own production/stock, did you consume from gifts or wage in kind. All questions were based on a one-week recall of food consumption.
[74] Consumption expenditures on health, education, durables and house expenses were excluded. Since almost all households are relatively poor, food shares in total consumption are very high (on average 89 percent in the study period), so we argued that food consumption is likely to give a good indication of overall consumption.

number of household members in each of the five categories (children ≤ 7 years, 8-18 years, 19-60 years, and > 60 years of age). It is hypothesized that more female and male adults in the household positively influence adoption of fertilizer and negatively influence consumption. More adult labor implies more labor is available for weeding facilitating adoption of fertilizer. On the other hand more adult labor availability could reduce consumption.

The variables used to estimate the transitory component of household income is district rainfall variability measured by the Gurgand index (for details on the computation of Gurgand index see Appendix 5.III of this thesis). We expect the transitory shock to be negatively related to consumption fluctuation if insurance is incomplete. Ownership of large livestock may have an important role in determining ex-ante fertilizer adoption and ex-post consumption smoothing behavior. The value of livestock was computed as the sum of value of cattle, horses, mules, camels, and donkeys. It is expected that value of large livestock could positively influence fertilizer adoption and consumption. On one hand, farmers with more large livestock may be more able to smooth consumption ex-post, and therefore, be more likely to adopt fertilizer. On the other hand, because they may have more access to draft power and manure there is less need for chemical fertilizer. Moreover, to investigate whether the effect of a rainfall shock on ex-post consumption varies with value of large livestock, we include interaction terms of the rainfall shock with value of large livestock.

There are two possible ways how rainfall affects fertilizer adoption. First, if households' expectation of rainfall variability is negative farmers are less likely to use fertilizer, as an ex-post consumption insurance motive. The limited ability of farm households to smooth consumption ex-post could limit adoption of fertilizer ex-ante. Second, when farmer's expectation of rainfall variability is positive then farmers are more likely to use fertilizer. Here, positive expected variability of rainfall and fertilizer adoption are complements.

To assess the impact of ex-ante fertilizer adoption on ex-post consumption smoothing behavior of households, consumption variability, which is measured as the coefficient of variation of consumption is included, which is the standard deviation divided by the mean[75]. The share of irrigated land, which measures a household's ability to deal with rainfall variability, is included as explanatory variable in the fertilizer adoption equation. Risk-aversion behavior of farm households has been argued to play an important role in ex-ante fertilizer adoption (Feder *et al.*, 1985). Farmer's risk-aversion variable is also included (for the computation of households risk attitude measures, see Chapter 4 of this thesis).

[75] Unlike the standard deviation and variance of a distribution, the coefficient of variation is not sensitive to scaling.

7.5 Results

Consumption Model

The fixed effect estimation results for the food consumption per adult equivalent are presented in Table 7.1. The $F-$test statistic of 7.57 indicates that the null hypothesis that all coefficients are zero is rejected at the 5 percent level.[76]

Table 7.1 shows that most explanatory variables have highly significant effects on food consumption. Rainfall variability measured by the Gurgand index is negatively and significantly related to food consumption, suggesting that households are unable to smooth food consumption in the face of rainfall variability or shock. The result suggests that with high rainfall variability food consumption is lower. The elasticity estimate indicates that a 1% increase in rainfall variability reduces consumption by 0.10%. The effect of rainfall variability on food consumption is partly offset by household ownership of large livestock as wealth indicator. The interaction effect of value of large livestock and rainfall variability is positive.

Table 7.1Fixed effect estimation results and elasticities of real consumption per adult equivalent

variable	Coefficient	z-value	Elasticities at mean value
Constant	319.31***	12.24	
Rainfall variability (Gurgand index)	-0.00*	-2.19	-0.10
Value of livestock	0.01***	3.79	0.21
Interaction term Rainfall variability with value of livestock	0.24	0.63	0.06
Children below 7 years of age	-21.82***	-4.09	-0.14
Household member between 8 and 18 years of age	-17.55***	-3.91	-0.15
Male adults (household member between 19 and 60 years of age)	-35.86***	-3.66	-0.18
Males above 60 years of age	-34.52*	-2.00	-0.03
Female adults (household member between 19 and 60 years of age)	-17.08*	-2.50	-0.08
Females above 60 years of age	-27.53	-1.55	-0.01
F(9,588) =7.57			
Prob>F=0.0000			

*Significant at 0.05 significance level; **significant at 0.01 significance level; ***significant at 0.001 significant level.

The effect of value of large livestock is as hypothesized positively and significantly related to food consumption. This suggests that food consumption increases with greater large livestock

[76] The Hausman (1978) test comparing random effect and fixed effects estimates was performed to determine whether the random effects estimator would have been appropriate. The test statistics of 24.30 is larger than the critical value $\chi^2_{9;0.95} = 16.92$. So it is concluded that there exists a correlation between at least one of the explanatory variables and the household specific effects, so that the random-effects estimator would give biased estimates.

ownership. As the value of livestock increases by 1% food consumption increases by 0.21%. The age/sex variables have the expected sign. Indicating food consumption per adult equivalent is negatively related to household size. Consumption per adult equivalent is significantly lower for households with a larger household size, suggesting that an additional household adult member leads to a less than proportional increase in food consumption, this result is in line with Deaton and Paxson, 1998.

Fertilizer Adoption Model

The unconditional logit fertilizer adoption model is presented in Table 7.2.[77] The likelihood ratio test result of 233.26 indicates that the null hypothesis that all coefficients are zero is rejected at the 5 percent significance level.

In line with our a priori expectations rainfall variability measured by the Gurgand index is negatively and significantly related to the probability of adopting fertilizer. The marginal effects suggest that if the Gurgand index increases by 1 unit the probability of fertilizer adoption declines by 0.10. This confirms that rainfall variability and fertilizer adoption move in the opposite direction. As a result high rainfall variability discourages farmers from using fertilizer, as an ex-ante income smoothing and ex-post consumption smoothing strategy.[78] The effect of the share of irrigated land is positively and significantly associated with the probability of fertilizer adoption. The probability of fertilizer use is greater with a higher share of irrigated land. Being a risk-averse farmer reduces the probability of fertilizer adoption, but not significantly.

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[77] A Hausman (1978) specification test for heterogeneity was performed to determine whether the unconditional logit estimator would be appropriate. Under the null hypothesis of homogeneity, both Chamberlain's conditional maximum likelihood estimator (CMLE) and the usual maximum likelihood estimator are consistent, but the CMLE is inefficient (Greene, 2003, p 699). The test statistic of 15.03 is smaller than the critical value $\chi^2_{11;0.95} = 19.68$. We can conclude that the null hypothesis of homogeneity is accepted. So the unconditional pooled logit estimate yields unbiased parameter estimates.

[78] Farmers resist to adopt fertilizer because they claim that fertilizer requires a high level of moisture and the returns are uncertain in a variable rainfall regime (from own field interview).

Table 7.2 Results of pooled logit estimation of the probability of fertilizer adoption

Variable	Coefficient.	z-value	Marginal effect
Constant	-0.34	-0.81	
Rainfall variability (Gurgand index)	-0.04***	-6.47	-0.10
Consumption variability	-0.71	-1.44	-0.18
Value of large livestock	0.00***	6.57	0.00
Risk aversiveness of household head	-0.02	-0.11	-0.01
Share of irrigated land	1.74***	5.56	0.43
Children below 7 years of age	0.13	1.47	0.03
Household member between 8 and 18years of age	0.23**	3.28	0.06
Male adult (age between 19 and 60)	0.48***	3.50	0.12
Male above 60 years of age	0.47	1.66	0.11
Female adult (age between 19 and 60)	0.07	0.34	0.02
Female above 60 years of age	1.09**	2.69	0.26
LR chi2(11)***	233.26		
Pseudo R2	0.22		
Log likelihood	-430.36		

*Significant at 0.05 significance level; **significant at 0.01 significance level; ***significant at 0.001 significant level.

Consumption variability, which is measured by its coefficient of variation, is negatively related to the probability of fertilizer adoption. The effect of the value of large livestock is, as hypothesized, positively correlated with the probability of fertilizer adoption, suggesting that large livestock serves as a means to absorb risks associated with fertilizer adoption. This result is consistent with Asfaw and Admassie (2004).

The effect of adult male members on the probability of adopting fertilizer is positive and significant, suggesting that male labor availability encourages fertilizer adoption., suggesting that fertilizer adoption requires substantial labor force.

Fertilizer Application Rates

The estimation of the Heckman selection model is presented in Table 7.3. The model is fitted with maximum likelihood estimation, with null hypothesis of no selection bias. The null hypothesis of no selection bias in the fertilizer application rate is rejected at 5% significance level.[79]

As expected rainfall variability is significantly and negatively related to the fertilizer application rate per hectare. The marginal effect suggests that a 1 mm increase in the variability of rainfall reduces the level of fertilizer application by 0.30 kg per hectare. Similarly, ex-post consumption variability is negatively and significantly related to the fertilizer application rate.

[79] Recent study by Asfaw and Admassie (2004) modelled fertilizer adoption decisions in isolation and estimated a logit model. This study ignores the potentially important fertilizer application rate decisions.

This means that ex-post consumption variability reduces fertilizer application rates per hectare. The marginal effects indicate that a 1 unit increase in consumption variability reduces the level of fertilizer application by 0.20 kg per hectare. Being a risk-averse farmer reduces fertilizer application rates per hectare.

Table 7.3 Tobit estimation of fertilizer application per hectare (kg per hectare)

Variable	Coefficient	z-value	Elasticity estimates at mean value
Constant	55.13	2.85	
Rainfall variability (Gurgand index)	-1.96***	-8.83	-0.30
Consumption variability	-9.87*	-2.01	-0.20
Value of livestock	0.00***	3.83	0.72
Risk aversiveness of household head	-4.83	-0.63	-0.13
Share of irrigated land	41.68***	4.85	0.30
Children below 7 years of age	-5.55	-0.59	-0.31
Household member between 8 and 18years of age	8.88**	2.78	0.85
Male adult (age between 19 and 60)	15.01**	2.61	0.78
Male above 60 years of age	36.57**	3.20	0.36
Female adult (age between 19 and 60)	5.03	1.28	0.38
Female above 60 years of age	23.02	1.37	0.07
Lambda	86.17***	3.80	
Wald Chi2 (11)***	138.19		
Number of observation	796		
Left censored observations	428		
Uncensored observations	368		

*Significant at 0.05 significance level; **significant at 0.01 significance level; ***significant at 0.001 significant level.

7.6 Discussion and Conclusions

This chapter analyzed the effect of rainfall and ex-post consumption variability on ex-ante fertilizer adoption using Tigray farm household surveys of 1996, 1997, 2001 and 2002. We estimated the binary adoption model and the level of fertilizer application per hectare and tested whether ex-post consumption risk affects fertilizer adoption and the level of fertilizer application. Moreover, food consumption per adult equivalence is also estimated to test whether food consumption is sensitive to transitory incomes (rainfall variability).

Our results show that food consumption per adult equivalence is very sensitive to transitory income shocks. The interaction between large livestock, as an indicator of wealth, and rainfall variability is important in explaining ex-post food consumption per adult equivalence. This suggests that large livestock is important in smoothing ex-post food consumption in the face of rainfall variability.

Ex-post consumption variability, which is measured by its coefficient of variation, is negatively correlated with ex-ante fertilizer adoption decisions and with the level of fertilizer application. This may be explained by the limited opportunities that exist in the study areas for ex-post consumption smoothing. Tigray farm households may then choose a strategy of smoothing income by adopting traditional farm technologies, which are less sensitive to rainfall fluctuations, with low variance of returns. Mitigating income risk through production technology choice can be costly, since typically expected profits must be sacrificed for lower risk (Morduch, 1995: 104). Costly income smoothing has implications for transforming semi-arid agriculture. This chapter has shown that farmers living in a semi-arid area are reluctant in adopting new technologies and taking advantage of new economic opportunities.

The availability of more adult members positively influences the probability of adopting fertilizer and fertilizer application per hectare. This result is consistent with the findings of Dercon and Christiaensen (2005).

A caveat of our analysis is that we only looked into the effect of ex-post consumption and rainfall variability on ex-ante fertilizer adoption. In particular, the risks related to poorly functioning markets and rural institutions such as output prices, demonstration trials on farmers' field, and transaction costs (access to good roads, information about prices and potential buyers) could also influence ex-ante fertilizer adoption.

Our results have important implications for development policy because ex-post consumption smoothing, reliable water availability for farming and fertilizer adoption can be viewed as complements.

Appendix 7.I Data

Table 7.I Descriptive Statistics

Variable	Observation	Mean	Std. Dev.	Min	Max
Dependent Variables					
Fertilizer adoption (=1 if households use fertilizer)	796	0.46	0.50	0	1
Fertilizer application per hectare (kg/hectare)	796	20.30	31.35	0	115
consumption per adult equivalent (kg/adult equivalence)	796	206..62	96.28	9.86	700
Independent Variables					
Rainfall variability (Gurgand index)	796	46.16	16.95	14.20	70.78
Value of livestock	796	3446.34	3568.125	0	25200
Risk aversion of head (=1 if risk-averse)	796	0.52	0.50	0	1
Share of irrigated land (hectare)	796	0.03	0.10	0	1
Children below 7 years of age	796	1.42	1.11	0	4
Household member between 8 and 18 years of age	796	1.91	1.32	0	7
Male adult (age between 19 and 60)	796	0.99	0.72	0	5
Male above 60 years of age	796	0.19	0.39	0	1
Female adult (age between 19 and 60)	796	1.04	0.41	0	3
Female above 60 years of age	796	0.05	0.22	0	1

Table 7.II Adult equivalent consumption units differentiated by age and gender

Age (years)	Male	Female
0-1	0.33	0.33
1-2	0.46	0.46
2-3	0.54	0.54
3-5	0.62	0.62
5-7	0.74	0.70
7-10	0.84	0.72
10-12	0.88	0.78
12-14	0.96	0.84
14-16	1.06	0.86
16-18	1.14	0.86
18-30	1.04	0.80
30-60	1.00	0.82
60 plus	0.84	0.74

Source: World Health Organization Data

Chapter 8
General Discussion and Conclusions

8.1 Introduction

Rainfall variability is often identified as the major risk faced by farm households in the arid and semi-arid regions of sub-Saharan Africa. This is immediately apparent for those who depend for the generation of their income upon farming. Differences in the timing, intensity and quantity of rainfall and other weather phenomena like storms, the incidence of disease and pest attacks on agricultural output can cause yields to fluctuate unpredictably. Variations in the price of inputs and marketed output cause farm profits to vary. Income fluctuations may lead to consumption fluctuations and this can be highly undesirable, especially when consumption shortfall may imply starvation. Since credit and insurance markets often do not exist or function imperfectly, rural farm households have developed mechanisms to buffer themselves from the effects of risk (Dercon, 2000). These include using assets as buffer stocks; and on-farm practices—such as intercropping and cropping in different plots—that minimize the translation of rainfall risk to yield risk (Carter, 1997). Moreover, diversifying their portfolio of activities can smooth income as well as decrease output fluctuations associated with both spatial and temporal variability in rainfall. This is often the case in semi-arid areas particularly in Northern Ethiopia Tigray, where drought or rainfall variability is a common phenomenon.

The objective of this thesis was, therefore, to examine farmers' attitudes toward risk, and to analyze ex-ante and ex-post responses to risk. Based on household and intertemporal choice models, a land allocation model, off-farm labor supply function and, consumption and fertilizer adoption models were developed in the preceding chapters to analyze households' ex-ante and ex-post risk management behavior econometrically. This study shows that one way to deal with rainfall induced risk is through crop diversification (Chapter 5) and use of conservative production strategies (Chapter 7). Another way is by relying on activity diversification, particularly off-farm employment (Chapter 6).

The objective of this chapter is threefold: (1) to discuss the nature of the data used and methodologies applied in the thesis chapters, (2) to present major findings of the chapters comprising the thesis, and (3) to derive policy implications and suggestions for future research outlook.

In section 8.2 the advantages and caveats of the data set and econometric methodology used in the preceding chapters is discussed. In section (8.3) the conclusions of the preceding chapters are summarized and information contained in these chapters is used to answer the research questions formulated in chapter 1. In section 8.4 policy implications that follow from both the theoretical and empirical findings of the thesis chapters are presented. Future research outlook is presented in section 8.5.

8.2 Data and Methodology

8.2.1 Data

The panel data set, which in this thesis was used, provides a rich source of information in analyzing household ex-ante and ex-post risk management strategies. First, panel data offer the scope to control for unobservable household specific effects (Baltagi, 2001). Second, data collected in panel setup provide more variability and reduce biases from aggregation over household observations. Third, panel data also give a larger sample size, which allows sufficient degrees of freedom in estimation and hence more powerful statistical inferences. To do so the 2001 and 2002 questionnaire was similar to the 1996 and 1997 questionnaire, with all the main items (crop production and input use, livestock ownership, household labor allocation, and food consumption) remaining unchanged. The advantage of the data we used for this thesis was that there is little sample attrition (0.01%) over the years.

A priori there is reason to suspect that respondents have an incentive to hide information if they do not trust the enumerators. To create certain mutual understanding and to develop trust, enumerators were employed from around the study village. In doing so data reliability was enhanced because respondents and enumerators knew each other.

After the data has been collected, enumerator teams checked each other's work thereafter the enumerators' supervisor carried out a second check. Data inconsistencies were corrected, either by referring back to the enumerators or, by revisiting the household.

8.2.2 Methodologies Applied

The theoretical model. The analysis in this thesis was focused on understanding farmers' decision making behavior under risk and their ex-ante and ex-post rainfall induced risk management strategies. Farmers' decision making behavior under risk was analyzed using neoclassical theory (expected utility) and non-expected utility theory (Prospect Theory). Farmers' ex-ante and ex-post risk management strategies were analyzed using neoclassical household models (Chapter 5 and Chapter 6).

Descriptive and comparative analysis of the data. A descriptive analysis and comparative analysis were employed in Chapter 2 and 4 respectively. In Chapter 2, the objective was to understand the data better and to describe the farming conditions and the characteristics of the farm households in the study areas. Based on a comparative analysis in Chapter 4 households were categorized into risk-averse and risk-lovers.

Choice experiments

To assess farmers risk attitude behavior binary hypothetical questions were offered to the head of the household. It was assumed that farmer's choice between the binary hypothetical questions was taken as an indication of his/her risk attitude behavior. The two hypothetical questions consisted of two possible outcomes with given probabilities. Each decision problem was a choice between a relatively safe and a relatively risky alternative. The low variance choice was considered as the safer option and the high variance choice was considered as the riskier option. To control for the behavior of risk-aversion of experimental subjects, the expected mean value of the riskier option was higher than that of the safest option. To minimize the order effects, the hypothetical questions were randomly arranged and randomly offered to the respondents.

Estimation methods used

In the empirical land allocation model of Chapter 5 the seemingly unrelated regression estimation technique (Zellner, 1962) was employed. In the presence of rainfall risk land allocation decisions are made jointly Ordinary Least Squares would therefore result in inefficiency, as it would ignore the correlation of error terms across equations.

Panel data estimation techniques. The two most frequently used panel estimators for continuous dependent variables are the random effects and the fixed effect estimators. The Hausman-Taylor instrumental variable estimator can be considered to be an estimator in between the fixed and random effects estimators. A Hausman test statistic is used to decide what estimation technique fits the data best. A Hausman test was carried out to distinguish between the random and fixed effects estimators in the off-farm labor supply equation (Chapter 6) and consumption equation (Chapter 7). Random effects, assuming that the explanatory variables are uncorrelated with the household specific error term, is rejected in favor of the fixed effect estimator. In the consumption equation (Chapter 7) we employed the fixed effects estimator. Here the main explanatory variables under examination were all time-variant, the fixed effects estimator fits well to the panel data. However, in the off-farm labor supply equation (Chapter 6) all time-invariant variables (such as education and district dummy) drop out of the model by the within transformation (deviation from individual means). Here a Hausman test was also carried out to compare the fixed effects estimator against the Hausman-Taylor estimation technique. The fixed effects estimator was rejected in favor of the Hausman-Taylor estimator. The fixed effect estimator does not allow the estimation of the coefficients of time-invariant variables (such as education and district dummy variables). However the time-invariant variables are of interest. To allow correlation between household specific effects and explanatory variables (including both time-varying and time-invariant variables) we employed the Hausman-Taylor instrumental variable estimation technique in the off-farm labor supply equation (see Chapter 6). Depending on their time variability and their relation to the household specific effects, the Hausman-Taylor estimation technique requires classifying the explanatory variables into four groups. In the off-farm labor supply equation the explanatory variable were classified as: time-invariant exogenous variables (such as district dummy), time variant exogenous variables (such as rainfall variability), time variant endogenous (such as seed price) and time-invariant endogenous variables (dummy household head education variable). It then uses the deviations from the means (within estimators) of the exogenous variables to instrument endogenous time-invariant variables. In addition, the Hausman-Taylor estimation technique does not require instruments excluded in the regression but, the instruments used are those included in the off-farm labor supply equation. The exogenous time-variant variables are used as instruments for estimating time-invariant endogenous variables. The time-varying endogenous variables are instrumented by their deviations from individual means. The model satisfies the identification requirement since the number of exogenous time-varying variables is bigger than the number of endogenous time-invariant variables (see Chapter 6 for details).

To estimate the fertilizer adoption model, Chamberlain's (1980) conditional maximum likelihood estimator (a variant of the panel data model estimation technique which was applied to continuous dependent variables) was tested against logit estimators. Like the standard random and fixed effects model, which was applied to continuous dependent variables, a Hausman test was applied to test whether there were household specific effects or not. If there would be no household specific effects, the model could be estimated using the usual logit estimator on pooled data (i.e. by unconditional maximum likelihood). The null hypothesis here was that there was no household specific effect. Here the null hypothesis was not rejected. The fertilizer adoption model was then estimated using the unconditional logit estimator.

8.3 Summary of Main Findings

Farmers decision making behavior under risk and the Independence Axiom. Using the answers to the hypothetical question offered to the household heads, we investigated farmer's decision making behavior using expected and non-expected utility theory. The result showed that, when farmers confronted with the sure gain and probability gain farm household heads tend to choose the sure gain rather than the probability gain (i.e. more than 80% of the subjects chose the sure gain). The study also reveals that about 51.5% of the subjects' choices were found to be consistent with the independence axiom of the expected utility theory. This result is consistent with the study of Hershey and Schoemaker (1980). They found no systematic prospect theory's reflectivity across subjects.

Farmers' risk-aversion and household socio-economic variables. None of the household head characteristics (age and literacy of the head) significantly influence risk-averse behavior of farmers. Household wealth (value of livestock) negatively related to the risk aversion behavior of farmers. That wealthier farmers are more risk taking is confirmed by this study. This finding is consistent with Rosenzweig and Binswanger (1993) and Yesuf (2004).

Crop Mix and rainfall variability. Rainfall variability is a major source of uncertainty surrounding the crop production environment and it varies across space and time. Crop yields are highly susceptible to variations in the timing and duration of the long rainy seasons (June-September). In missing and incomplete markets for insuring ex-post risk against rainfall variability, farm households mainly depend on diversity of their crops for their own food and fodder they use. Rainfall variability directly translates to farm income variability, as subsistence agricultural production is almost exclusively dependent on the long rainfall season. Rainfall variability has a negative effect on the probability of growing crops and on the proportion of land allocated to wheat and lentil. Results for the probability of choosing crops to be grown show that if the rainfall variability, which was measured by the coefficient of variation of the long rainfall season, increases by 1 unit, the probability of growing wheat and lentil decreases by 0.13 and 0.10 respectively. If the rainfall turns out to be low wheat and lentil are not chosen to be grown and the proportion of land allocated to these crops declines. These crops are known to be sensitive to variability in rainfall. Variability of rainfall positively relates to the proportion of land allocated to teff, barley and grass pea. Rainfall variability and production of teff, barley and grass pea seem complementary. It is confirmed that farmers' ex-ante strategic responses to rainfall induced risk are to favor drought resistance crops and varieties. Farm households allocate the available cultivated land to different crops to minimize the variability of farm income flows (see

Chapter 5). On-farm diversification, fragmentation of landholdings into many plots, and growing different crops can also offer a way of diversifying income (Reardon *et al*., 1992).

Crop Mix and family size. Farm households rely almost exclusively on their own manpower for crop production. Family size positively influences production of wheat, teff and barley. These crops are known to be the most labor demanding crops. Family size is negatively related to grass pea production, a crop that requires little labor for production. This result is consistent with the findings of Woldehanna (2000).

Off-farm labor supply and rainfall. Off-farm supply of labor is an important mechanism for smoothing income in the presence of negative shocks to farm production. In a non-dynamic environment as Tigray, Northern Ethiopia, rainfall variability positively influences off-farm supply of labor (Chapter 6). In response to a 1 unit increase in the variability of rainfall (Gurgand index) the number of hours worked off-farm increases by 9.32. If farm households expect more variability in rainfall more labor is allocated off-farm and less labor on-farm. This is consistent with the presence of a precautionary or portfolio effect of rainfall-induced risk on labor supply. The portfolio effect implies that households diversify their income generating activities to off-farm employment to minimize the effect of rainfall-risk on income. Similarly the number of hours supplied off-farm increases by 0.98 if the annual rainfall deviations from the 10 year period mean rainfall increase by 1 mm. The result could be interpreted as when the realization of rainfall deviation from the 10 period is high farm income is low and the household increases off-farm labor in order to smooth household income. Evidence from India (Rose, 2001; Kochar, 1999; and Walker and Ryan, 1990) also suggests that off-farm income is an effective income and consumption smoothing strategies in semi-arid areas.

Off-farm labor supply and family size. Off-farm hours supplied increase with family size. In this study it is confirmed that, the larger the family size the greater the probability of participating in off-farm work and the longer the hours worked. A large family size has a tighter budget constraint thus a higher need for additional income. On the other hand as farm size is small in the study areas, higher family size means that more labor is available for on-farm production, then marginal on-farm labor productivity declines and more labor could be supplied off-farm (Chapter 6). This result is consistent with results from other studies in Africa that is the probability of engaging in off-farm work and off-farm hours worked are positively and significantly related to family size (Matshe and Young, 2004; Woldehanna and Oskam, 2001).

Ex-post consumption and transitory income. Transitory income, as represented by variability of rainfall, has a significant negative effect on ex-post food consumption per adult equivalence. The result suggests that in the face of income variability households are unable to smooth food consumption (see Chapter 7). This result is consistent with the findings of Ersado *et al*. (2004).

Ex-ante adoption of fertilizer and ex-post consumption variability. An important result is that consumption variability, as represented by the coefficient of variation on consumption, has a negative effect on the probability of adoption of fertilizer and on the level of fertilizer application per hectare. This result confirms expectations in that increases in the variability of ex-post consumption significantly reduce the application of fertilizer. The marginal effect suggests that ex-post consumption variability reduces the level of fertilizer application per hectare by 0.20 kg. This finding may suggest, at least for this sample, that ex-post consumption variability reduces possible welfare gains from adoption of fertilizer and inhibits agricultural transformation from subsistence to market oriented commercial farms.

Ex-ante fertilizer adoption and farmers' risk-aversion. Being a risk-averse farmer reduces the probability of adoption of fertilizer and level of application of fertilizer per hectare. Although fertilizer is a highly productive input, in the presence of rainfall-induced risk farmers use less fertilizer (Bliss and Stern, 1982). The result suggests that in the absence of formal credit and insurance markets, one way of smoothing ex-ante income and ex-post consumption is to reduce fertilizer application per hectare. However, no significant relationship between risk-averse behavior of farmers and probability of adoption of fertilizer and level of fertilizer has been revealed.

Ex-ante fertilizer adoption and rainfall variability. Rainfall variability is negatively and significantly linked to ex-ante fertilizer adoption and level of fertilizer application per hectare. The results suggest that expectation in that increases in the variability of rainfall significantly reduce the probability of adoption of fertilizer and level of fertilizer application per hectare. The result confirms that in the study areas, where rainfall variability is substantial, farmers choose traditional inputs over fertilizer in order to lower risk ex-ante. To this end, any mechanism that allows farmers to smooth income ex-post could raise the use and adoption of fertilizer.

In sum, the neoclassical agricultural household model was found to be a suitable theoretical model for the study of farm households' land allocation (Chapter 5) and off-farm labor supply decisions (Chapter 6). If both ex-ante and ex-post variability of rainfall increases, farm households allocate more land to the drought resistance crop (Chapter 5) and allocate more labor to off-farm work (Chapter 6). This result is consistent with the neoclassical theory of farm households. If variability of income in one labor employment opportunity is greater than in the other more labor is allocated to the less risky labor employment alternative such that expected marginal returns are equal between the alternatives (see also Rose, 2001 and Kochar, 1999).

The ex-ante fertilizer adoption and ex-post consumption model in Chapter 7 was derived from an inter-temporal choice model. Using the permanent income and life-cycle hypothesis, we tested if consumption is sensitive to transitory shocks. The evidence indicates that consumption is very sensitive to transitory shocks. The data did not support the permanent income hypothesis. This is consistent with the results of Dercon and Christiaensen (2005) and Kazianga and Udry (2006).

8.4 Policy Implications

The high degree of income variability Tigray farm households face despite the costs they make to deal with rainfall shocks raises the question what kind of policy interventions could enhance household risk management and risk coping strategies. Some of these intervention strategies are of long-term concern, whereas some of them are of an immediate necessity to reduce the prevailing food insecurity, which is induced by high rainfall variability in the region. A wide range of intervention strategies might be considered but here I limit myself to options, which follow from the research outcomes of this thesis.

The ability of Tigray farm household's to adapt crop production and off-farm labor supply decisions according to rainfall variability is the basis for their survival in this high-risk environment. This study has shown that by: (1) growing a mix of different crops and drought resistant crops, (2) supplying labor to off-farm work, and (3) reducing the probability of adoption of fertilizer and level of fertilizer application are all strategies farmers adapt to manage and cope with farm income uncertainties.

Strengthening farmers' capacity to manage rainfall-induced shocks could be done either by helping them to better mitigate the effects of shocks (e.g. introducing small-scale irrigation schemes, water harvesting techniques, and introduction of more drought resistance crop varieties) or by increasing their capacity to cope with shocks ex-post (e.g. development of off-farm employment work opportunities).

Given the importance of crop production and off-farm employment in providing livelihoods for the majority of the farm households in Tigray, it is clear that addressing the vulnerability of crop production to rainfall-induced shocks and promoting off-farm employment is crucial. To this end, the strategies to reduce ex-ante income variability and ex-post consumption variability are to stabilize farmers income through (i) the promotion of small-scale irrigation and rainwater harvesting techniques as supplementary irrigation, (ii) the introduction of drought resistance crops, and (iii) the expansion of off-farm work opportunities. From this thesis the following four policy interventions deserve particular attention:

Supplemental irrigation. Unreliable rainfall is the leading cause for low utilization of fertilizer and of harvest failure in Tigray region. Investments in irrigation may give more assured levels of crop production. The role of rainfall variability in this study suggests that policies to reduce both the overall level of rainfall-induced risk to which households are exposed, as well as policies to reduce the component of covariant risk in that overall level would be both equity and productivity improving. Such programs would include introduction of rain-water harvesting techniques, and small-scale irrigation development.

Introduction of drought resistant and early maturing crops. Researching and supplying appropriate crop production inputs and technologies for highly rainfall variable areas such as drought tolerant, short cycle and relatively high yielding crop varieties that fit farmers requirements will be important. For example, introduction of Enset[80], cassava and other root crops will be important to overcome farmers' income variability.

Expansion of off-farm employment activities. Off-farm employment activities need to be encouraged. Minimizing constraints in the off-farm labor markets would need to facilitate an appropriate off-farm supply response and maximize the production and consumption linkage effects. Moreover, as already seen in Chapter 6 off-farm income would help supplement crop production for farmers as a coping mechanism against crop failures. Promoting employment generation schemes or food for work could be alternatives for farmers to cope with crop shortfalls.

To conclude, expansion of supplementary irrigation, introduction of drought resistance and short cycle varieties of crops, and expansion of off-farm employment activities, would enable farm households to manage and cope with rainfall-induced risks. This intervention could help in transforming the semi-subsistence agriculture.

8.5 Future Research Outlook

Based on the analysis made on this thesis, it is warranted to suggest areas requiring further research. A follow-up research is suggested to address the following issues.

Risk and vulnerability to poverty. To obtain a full understanding of farm households' risk attitudes and risk perceptions, it is necessary to complement the findings of this research with an analysis of the nature and degree of household vulnerability to poverty, particularly vulnerability

[80] A staple food crop, commonly known as false banana

to consumption. Research on risk and vulnerability to poverty in a wider area may enable to identify the group of households that are most vulnerable to rainfall-induced shocks.

Supplementary irrigation and household income smoothing. The relationship between risk reducing and risk mitigation enhancing strategies, such as expansion of small scale irrigation and rainwater harvesting techniques, and poverty reduction need to be examined. This would enable us to analyze the impact of supplementary irrigation on households' resource allocation and on household welfare.

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Summary

A distinctive feature of life in Tigray (a region in Northern Ethiopia) is the importance of rainfall variability. This is immediately apparent for those who depend upon farming for their livelihoods. Differences in timing, intensity and amount of rainfall and the incidence of disease, and pests cause farm incomes to fluctuate unpredictably. Rainfall variability not only affects crop mixes grown, it has also an effect on off-farm labor supply decisions and on the decision to use fertilizer. Thus understanding farmers' behavior in making economic decisions under rainfall variability is crucial to identify the opportunities and constraints faced by rural farm households in smoothing consumption. The objective of this research is to examine the impact of rainfall variability on the economic decisions of farm households in Tigray.

In the research econometric models, based on neo-classical household production and consumption models and intertemporal choice models, are used to analyze the economic decisions of farmers under rainfall variability. These methods are applied to a four-year (1996, 1997, 2001, and 2002) panel data of Tigray farm households.

Chapter 2 introduces the data set used in this thesis. Using a descriptive data analysis, this chapter describes the socio-economic characteristics of farm households in the study area, Hintalo-Wajerat and Enderta districts in Tigray. We discuss income composition, crop choice, input use, credit, and land markets. The data is disaggregated based on the number of oxen owned by the household. Households in the study area are dependent on cropping, off-farm wages, off-farm self-employment, and non-labor income for their livelihoods. The chapter identifies that the degree of dependence on these activities varies according to the socio-economic status of the household. Better-off households with more than two oxen, for example, are less reliant on off-farm wage employment and non-labor income (such as food aid) than those who are considered poorer (i.e. with less than two oxen or no oxen). During the research period farmers were exposed to three droughts (in 1997, 2000 and 2002), making rainfall a major source of risk. In general the use of commercial fertilizer in the study area is very low. However fertilizer use increases with the number of oxen owned by the household. Only 28% of the poor households are using fertilizer in the study period. Further, the poor enter into activities and asset portfolios with low risk, but also low returns, affecting their long-term income negatively. The better-off households invest into profitable but more risky activities (use of purchased inputs and trading).

The theoretical literature on how individuals make decisions under risk is reviewed in **Chapter 3**. This chapter gives an overview of the expected utility theory and its caveats and prospect theory, one of the possible alternatives for the expected utility theory. The von Neumann-Morgenstern expected utility theory with its normative axioms, if obeyed, makes

individuals behave as if they are maximizing expected utility. The von Neumann-Morgenstern expected utility theory expresses preferences over lotteries in the same way as in economic theory preferences over goods under certainty are expressed. Lotteries are representations of risky or uncertain, mutually exclusive alternatives.

The chapter further reviews the axioms of the von Neumann and Morgenstern expected utility theory. The literature identifies three main axioms: the independence axiom, the continuity, and order or completeness axiom. The order and continuity axiom are essential to establish the existence of a continuous preference function over probability distributions. It is the independence axiom which gives the theory its empirical content and power in determining rational behavior. If an individual obeys the expected utility axioms, then a utility function can be formulated that reflects the individual preferences.

The chapter also discusses and reviews an alternative theory of individual decision making under risk - the prospect theory. Prospect theory argues that choices that individuals make in risky situations exhibit several characteristics that are inconsistent with the basic axioms of expected utility theory. For example, in prospect theory individuals attach less value to probable outcomes in comparison with certain outcomes. The decision theory reviewed in this chapter is tested in **Chapter 4**.

Using the farm households' heads responses to hypothetical questions **Chapter 4** presents farmers' attitudes to risk and factors affecting the farmers' risk attitudes. Comparative statistics are used to analyze farmers' risk preferences. Based on the analysis farmers are classified as risk averse and risk loving.

The results show that more than 80 percent of the farmers choose the certain choice rather than the gamble, although the mean gain for the gamble is larger. For the sure loss and probabilistic loss question, almost half farmers choose the sure loss. This finding is in contrast with most of the findings of experimental studies with students as subjects. This choice pattern indicates that preferences between negative prospects are not the mirror image of the preferences between positive prospects.

To get more insight on the decision behavior of farmers under risk, the result is disaggregated by districts. The results on the shape of the utility function by district indicate that the vast majority is classified as showing a concave utility for gains, 89% and 76% of subjects in Enderta and Hintalo-Wajerat respectively. In Enderta about 64% subjects exhibit a convex utility for losses. This empirical finding is consistent with most of the findings in the psychology literature. However, in Hintalo-Wajerat a significant proportion (about 71%) of subjects exhibit concave utility for losses. This finding is not according to what prospect theory suggests.

A logit model is used to identify the factors that influence farmers' safest choice. Accordingly, none of the household head characteristics (age and education) significantly influence risk attitude behavior. Household wealth has a significant and negative influence on the risk preferences of the household heads. District dummy, year dummies, and district mean rainfall variables also significantly influence the risk attitude of farmers.

The empirical Chapters 5-7 draw upon an agricultural farm household model that incorporates the production, consumption, and labor supply decisions of farm households. **Chapter 5** analyzes the farm household ex-ante responses to rainfall variability. Farm households grow a different mix of crops to cope with rainfall-induced shocks. A probit is used to determine the probability that a crop is selected. Zellner's (1962) estimation technique for seemingly unrelated regressions (SUR) has been used in the land allocation model. In the land allocation model rainfall variability variables are included in addition to the usual variables (such as variable input prices and amount of labor).

The results show that rainfall variability negatively influences the proportion of land allocated to wheat and lentil. Both crops require relatively high and reliable rainfall. For teff, barley, and grass pea the effect of rainfall variability is positive. If rainfall is low and unreliable then teff, barley and grass pea are planted in August, the last month of the rain season. This implies that the proportion of land allocated to crops adjusts with rainfall variability.

This chapter shows that rainfall variability has an impact on the probability of choosing crops and on the proportion of land allocated to crops. The empirical results from this chapter suggest that an increase in application of irrigation and rainwater harvesting techniques as ex-ante risk management strategies would minimize the effect of rainfall variability.

In the absence of credit and insurance markets rural households use off-farm labor as an ex-ante and ex-post income smoothing mechanism. **Chapter 6** analyzes the effect of rainfall on farm household's off-farm labor supply decisions. The Hausman-Taylor instrumental variable estimator is used to answer the research question. This technique combines the desirable properties from the fixed effects and random effects estimators. The Hausman-Taylor estimator enables to include time-invariant variables that are farm specific in estimation such as a district dummy and household head education. The results show that rainfall variability is positively correlated to the off-farm work participation decision and to the number of hours worked. This finding suggests that high rainfall variability, as indicator for expected risk, encourages households to engage in off-farm work as an income and consumption smoothing strategy. Value of livestock is negatively correlated with off-farm work participation. As livestock value is a proxy for wealth, the negative relationship explains that relatively wealthy households are less likely to participate in off-farm work. This finding is consistent with the general belief that livestock is used as an income and consumption smoothing strategy in developing countries. The probability of off-farm employment participation and hours worked positively increases with family size. This suggests that larger households cannot realize sufficient farm income thus having a higher need for additional income. Another reason could be that a large family size results in a low on-farm marginal productivity of labor. The results in this chapter illustrate the need for well functioning labor markets.

The most important way of raising farm income in developing countries is the adoption of new production technologies, especially chemical fertilizer and high-yielding varieties of seed. Risk aversion of farmers and absence of credit and insurance markets for ex-post consumption smoothing inhibit the adoption of new farm technologies. **Chapter 7** analyzes the relationship between ex-post consumption fluctuation and the adoption of fertilizer. A fixed effects estimator and logit model estimator for the adoption decision of fertilizer are used. The results show that rainfall variability is negatively and significantly related to the probability of adopting fertilizer. This confirms that rainfall variability and fertilizer adoption move in the opposite direction. This suggests that high rainfall variability discourages farmers from using fertilizer as ex-ante income smoothing and ex-post consumption smoothing strategies. Consumption variability is negatively related to the probability of fertilizer adoption decisions. This may be explained by the limited opportunities that exist in the study areas for ex-post consumption smoothing mechanisms. Tigray farm households may then choose a strategy of smoothing income by adopting traditional farm technologies, which are less sensitive to rainfall fluctuations. This result has implications for development policy. Here ex-post consumption smoothing, reliable water availability for farming and fertilizer adoption can be viewed as complements. These complementarities suggest that policies that focus on rainwater harvesting techniques and promotion of small-scale irrigation would promote fertilizer adoption. This could increase farm household income and could create opportunities for ex-post consumption smoothing.

Samenvatting

Kenmerkend voor leven in Tigray (een regio in het noorden van Ethiopië) is de afhankelijkheid van regenval en de schommelingen in regenval. Dit geldt vooral voor degenen die afhankelijk zijn van de landbouw voor hun dagelijks bestaan. Schommelingen in tijdstip, intensiteit en hoeveelheid regenval én dier- en plantziekten maken dat inkomens die in de landbouw worden verdiend op onvoorspelbare manier variëren. Schommelingen in regenval beïnvloeden niet alleen de gewaskeuze maar ook het al dan niet werken buiten het bedrijf en de beslissing al dan niet kunstmest te gebruiken. Het is van belang te weten hoe agrarische huishoudens productie- en consumptiebeslissingen nemen bij grote schommelingen in regenval om de mogelijkheden en beperkingen leren te kennen die zij hebben ten aanzien van het stabiliseren van hun consumptie. Het doel van dit onderzoek is om de gevolgen na te gaan van de schommelingen in regenval voor de economische beslissingen van agrarische huishoudens in Tigray.

In het onderzoek is gebruik gemaakt van econometrische modellen, gebaseerd op neo-klassiekke huishoudproductiemodellen and inter-temporele keuzemodellen, om economische beslissingen van agrarische huishoudens in het geval van schommelingen in regenval te onderzoeken. De modellen zijn toegepast op een vierjarige (1996, 1997, 2001, en 2002) panel dataset van agrarische huishoudens in Tigray.

Hoofdstuk 2 beschrijft de dataset die wordt gebruikt in dit proefschrift. Het hoofdstuk bespreekt de sociaal-economische kenmerken van agrarische huishoudens in de twee studiegebieden, de districten Hintalo-Wajerat en Enderta in Tigray. Zo komen aan de orde: de inkomenssamenstelling, gewaskeuze, inputgebruik, gebruik van krediet en grondmarkten. Bij de bespreking worden de huishoudens opgedeeld op basis van het aantal ossen dat ze bezitten. Ossen zijn een belangrijke indicatie voor de welvaart van een huishouden. Huishoudens in de studiegebieden zijn voor hun inkomen afhankelijk van akkerbouw, arbeidsinzet buiten het bedrijf, nevenactiviteiten en inkomenstransfers van buiten het bedrijf (bijvoorbeeld voedselhulp). Het hoofdstuk laat zien dat de afhankelijkheid van de afzonderlijke activiteiten afwijkt voor huishoudens met een verschillend welvaartsniveau. Welvarende huishoudens, met meer dan twee ossen, zijn bijvoorbeeld minder afhankelijk van lonen die buiten het bedrijf worden verdiend en inkomenstransfers van buiten het bedrijf dan minder welvarende huishoudens (met één of geen ossen). Gedurende de onderzoeksperiode waren de huishoudens blootgesteld aan drie droogtes (in 1997, 2000 en 2002) wat er toe leidde dat regenval de belangrijkste bron van risico was in de onderzoeksperiode. In de studiegebieden wordt weinig kunstmest gebruikt. Het kunstmestgebruik stijgt met het aantal ossen (welvaartsniveau) dat in het bezit is van een huishouden. Slechts 28%

van de armste huishoudens gebruikte kunstmest in de onderzoeksperiode. Verder blijkt dat de armste huishoudens zich bezighouden met activiteiten die weinig risico met zich mee brengen maar ook een lage opbrengst hebben. Dit heeft een negatieve invloed op hun lange termijn inkomen. De rijkste huishoudens participeren in meer risicovolle activiteiten (bijvoorbeeld het gebruik van meer aangekochte inputs; handel).

Hoofdstuk 3 bespreekt de literatuur over hoe individuen beslissingen nemen onder risico. Het hoofdstuk geeft een overzicht van de 'verwachte nutstheorie' en haar nadelen én 'prospect (verwachtingen) theorie', één van de mogelijke alternatieven voor de verwachte nutstheorie. De von Neumann-Morgenstern verwachte nutstheorie met zijn normatieve axioma's leidt, indien aan de aximona's wordt voldaan, tot nutsmaximalisatie bij individuen. De von Neumann-Morgenstern verwachte nutstheorie geeft de voorkeuren voor alternatieve loterijen op dezelfde wijze weer als in de economische theorie voorkeuren voor goederen onder zekerheid worden weergegeven. Loterijen zijn weergaven van onzekere, elkaar uitsluitende alternatieven.

Het hoofdstuk gaat verder in op de axioma's van de von Neumann-Morgenstern verwachte nutstheorie. In de literatuur worden drie axioma's genoemd: het onafhankelijkheids, continuïteits, én volgorde of volledigheids axioma. Het volgorde en continuïteits axioma zijn essentieel om het bestaan van een continue voorkeursfunctie vast te stellen. Het onafhankelijkheids axioma geeft de theorie empirische inhoud en kracht door rationeel gedrag te bepalen. Als een individu voldoet aan de axioma's dan kan een nutsfunctie worden geformuleerd die de individuele voorkeuren weergeeft.

Het hoofdstuk bespreekt ook een alternatieve theorie van het nemen van beslissingen onder risico: de prospect theorie. De prospect theorie stelt dat keuzen die individuen maken onder risico kenmerken vertonen die inconsistent zijn met de axioma's van de verwachte nutstheorie. De prospect theorie laat bijvoorbeeld zien dat individuen minder gewicht hechten aan onzekere uitkomsten dan aan zekere uitkomsten. In **hoofdstuk 4** worden de besproken theorieën getest.

Met behulp van de antwoorden van bedrijfshoofden op hypothetische vragen bespreekt **hoofdstuk 4** de risicohouding van agrariërs én de factoren die de risicohouding beïnvloeden. Beschrijvende statistiek wordt gebruikt om de risicohouding van agrariërs te analyseren. Op basis hiervan worden agrariërs verdeeld in risicomijdend of risicozoekend.

De resultaten laten zien dat meer dan 80% van de agrariërs de zekere in plaats van de onzekere uitkomst (de gok) kiezen. In het geval van een zeker of onzeker verlies kiest bijna de helft van de agrariërs voor het zekere verlies, ook al is de gemiddelde verwachte waarde van de uitkomst hoger bij de onzekere keuze. Dit laatste resultaat is in tegenspraak met de uitkomsten van de meeste experimentele studies met studenten. De uitkomsten laten zien dat de keuze van agrariërs voor negatieve uitkomsten niet het spiegelbeeld is van de keuze voor positieve uitkomsten.

Om meer inzicht te krijgen in de beslissingen onder risico worden de resultaten in de twee districten met elkaar vergeleken. Kijkend naar de vorm van de nutsfunctie blijkt die voor 89% van de agrariërs in Enderta en 76% van de agrariërs in Hintalo-Wajerat concaaf voor winsten te zijn. In Enderta blijken 64% van de agrariërs een convexe nutsfunctie voor verliezen te hebben. Deze uitkomsten zijn consistent met wat wordt gevonden in de psychologie literatuur. In Hintalo-Wajerat blijkt een significant deel (71%) van de agrariërs een concave nutsfunctie voor verliezen te hebben. Deze uitkomst is in tegenspraak met wat de prospect theorie voorspelt.

Een logit model is gebruikt om de factoren te identificeren die de risicohouding van agrariërs bepalen. Geen van de huishoudkenmerken (leeftijd en opleiding) blijkt die risicohouding significant te bepalen. Het welvaartsniveau van het huishouden blijkt wel een significante en negatieve invloed te hebben op de risicohouding. District, jaar en de gemiddelde regenval per district bepalen eveneens de risicohouding van agrariërs.

De empirische hoofdstukken 5-7 zijn gebaseerd op een huishoudproductiemodel waarin beslissingen over productie, consumptie en arbeidsaanbod zijn opgenomen. **Hoofdstuk 5** analyseert de ex-ante reactie van huishoudens op schommelingen in regenval. Agrarische huishoudens verbouwen een mix van gewassen om voorbereid te zijn op droogte. Een probit model is gebruikt om de kans te bepalen dat een gewas wordt verbouwd. De seemingly unrelated regression (SUR) techniek is gebruikt om de factoren te bepalen die de allocatie van grond over de gekozen gewassen beïnvloeden. In de functie die grond toewijst aan de gewassen zijn naast de gebruikelijke variabelen (bijvoorbeeld de prijzen van variabele inputs en de hoeveelheid arbeid) de schommelingen in regenval opgenomen.

De resultaten laten zien dat grote schommelingen in regenval de hoeveelheid grond die wordt gebruikt voor de verbouw van tarwe en linzen negatief beïnvloedt. Beide gewassen vereisen een relatieve grote en betrouwbare regenval. Voor teff, gerst en grass pea is het effect van grote schommelingen in regenval positief. Geringe en onbetrouwbare regenval zorgen er voor dat teff, gerst en grass pea in augustus, de laatste maand van het regenseizoen, worden geplant. Dit leidt er toe dat de aandelen van de gewassen in het landareaal reageren op schommelingen in regenval.

Dit hoofdstuk laat zien dat schommelingen in regenval een invloed hebben op de kans dat een bepaald gewas wordt verbouwd én de hoeveelheid grond die aan de gekozen gewassen wordt toegewezen. De empirische resultaten in dit hoofdstuk suggereren dat een toename in de toepassing van irrigatie en technieken voor het opvangen van regenwater, als ex-ante risico management strategieën, de effecten van schommelingen in regenval kunnen minimaliseren.

Bij afwezigheid van krediet- en verzekeringsmarkten is het werken buiten het bedrijf een ex-ante en een ex-post strategie voor agrarische huishoudens om inkomensschommelingen te ondervangen. **Hoofdstuk 6** analyseert het effect van schommelingen in regenval op de beslissing van agrarische huishoudens om buiten het bedrijf te gaan werken. De Hausman-Taylor instrumentele variabelen schatter is gebruikt om deze onderzoeksvraag te beantwoorden. Deze techniek combineert de gewenste eigenschappen van de vaste effecten en willekeurige effecten schatters. De Hausman-Taylor schatter maakt het mogelijk om tijdsonafhankelijke bedrijfsspecifieke effecten zoals een district dummy of opleidingsniveau mee te nemen in de schattingen. De resultaten laten zien dat grote schommelingen in regenval het werken buiten het bedrijf én het aantal gewerkte uren buiten het bedrijf positief beïnvloedt. Dit resultaat suggereert dat een grote schommelingen in regenval, als indicator voor een groot verwacht risico, huishoudens doet besluiten om buiten het bedrijf te gaan werken als een manier om inkomen en consumptie te stabiliseren. De waarde van de veestapel is negatief gecorreleerd met buiten het bedrijf werken. De waarde van de veestapel is een indicator voor de welvaart van een huishouden, daarom laat de negatieve relatie zien dat relatief welvarende huishoudens minder snel buiten het bedrijf werken. Deze uitkomst is consistent met de algemene opinie dat vee wordt gebruikt om inkomens en consumptie te stabiliseren in ontwikkelingslanden. De kans om buiten het bedrijf te werken en het aantal buiten het bedrijf gewerkte uren neemt toe met de omvang van het gezin. Dit suggereert dat grotere gezinnen onvoldoende inkomen realiseren op het bedrijf wat de behoefte aan extra inkomen verklaart. Een andere reden kan zijn dat een groot gezin leidt tot een lage marginale arbeidsproductiviteit. De gevonden resultaten in dit hoofdstuk illustreren de noodzaak van goed functionerende arbeidsmarkten.

Het belangrijkste middel om agrarische inkomens in ontwikkelingslanden te laten stijgen is de adoptie van nieuwe productietechnologieën, vooral kunstmest en zaden met een hoge opbrengst. Risicoaversie van agrariërs en de afwezigheid van krediet- en verzekeringsmarkten, om ex-post de consumptie te stabiliseren, verhinderen de adoptie van nieuwe productietechnologieën. **Hoofdstuk 7** analyseert de relatie tussen ex-post consumptie stabilisatie en de adoptie van kunstmest. In dit hoofdstuk worden een vaste effecten schatter én een logit model voor de beslissing om kunstmest te gebruiken toegepast. De resultaten laten zien dat de variatie in regenval negatief en significant gecorreleerd is met de kans dat kunstmest wordt gebruikt. Dit bevestigt dat grote schommelingen in regenval leiden tot een geringer gebruik van kunstmest. Een grote variatie in regenval ontmoedigt agrariërs kunstmest te gebruiken als een ex-ante strategie om inkomen te stabiliseren en een ex-post strategie om consumptie te stabiliseren. Variatie in consumptie is negatief gecorreleerd met de kans dat kunstmest wordt gebruikt. Dit kan verklaard worden door de geringe mogelijkheden die agrariërs in de studiegebieden hebben om ex-post hun consumptie te stabiliseren. Huishoudens in Tigray kiezen daarom wellicht voor traditionele productietechnieken, die relatief ongevoelig voor schommelingen in regenval zijn, om daarmee hun inkomen te stabiliseren. Dit resultaat heeft gevolgen voor het ontwikkelingsbeleid. Ex-post consumptie stabilisatie, betrouwbare beschikbaarheid van water en de adoptie van kunstmest zijn complementen van elkaar. Dit suggereert dat de promotie van irrigatie en technieken om regenwater op te vangen kunstmestgebruik stimuleren. Dit kan leiden tot een vergroting van de huishoudinkomens en creëert mogelijkheden om ex-post consumptie te stabiliseren.

Completed Training and Supervision Plan

Name of the sourse	Department/Institute	Year	Credits[81]
I. General part			
Scientific writing	Wageningen University	2001	1
Basic statistics	Wageningen University	2001	1
Subtotal part I (Max 4 Credits)			**2**
II. Mansholt-specific part			
Mansholt introductory course	Mansholt Graduate School	2001	1
Social science research	Mansholt Graduate School	2001	1
Multi-agent system	Mansholt Graduate School	2001	1
Mansholt multidisciplinary seminar	Mansholt Graduate School	2005	1
Subtotal part II (max. 6 Credits			**4**
III. Discipline-specific part			
Advanced econometrics	Tinbergen Institute, The Netherlands	2000	4
Applied research in action	Tinbergen Institute, The Netherlands	2000	2
Applied policy analysis	Netherlands Network of Economics (NAKE)	2000	2
Macroeconomics	Tinbergen Institute, The Netherlands	2001	4
Optimization methods in econometrics	Netherlands Network of Economics (NAKE)	2001	2
Environmental economics	Netherlands Network of Economics (NAKE)	2001	2
The Economics of household behavior	Netherlands Network of Economics (NAKE)	2001	2
NAKE workshop (June 2001)	Netherlands Network of Economics (NAKE)	2001	2
Behavioral economics	Mansholt Graduate School	2001	2
NAKE Workshop (June 2004)	Netherlands Network of Economics (NAKE)	2004	2
Econometrics of panel data	Netherlands Network of Economics (NAKE)	2004	2
Agricultural models	Wageningen University, The Netherlands	1996	5
Econometrics II	Wageningen University, The Netherlands	1996	3
Subtotal part III (min 9 credits)			**34**
Total (min. 20 Credits)			**40**

[81] One credit is equivalent to 40 hours of course work.

Curriculum Vitae

Nigist Haile Abreha was born on October 31, 1967 in Tigray, Ethiopia. She studied at Alemaya University, Ethiopia from September 1984 to July 1988 and obtained a BSc degree in Agricultural Economics. From September 1988 to July 1995 she worked at the Bureau of Agriculture as project monitoring and evaluation expert in the planning and programming department and served in various capacities. In particularly she was involved in various socio-economic and agricultural extension impact assessment studies. From August 1995 to March 1997 she participated in the Netherlands Fellowship Program and did her MSc in Agricultural Economics and Marketing with specialization Development Economics at Wageningen Agricultural University, The Netherlands. Upon return she worked as a project coordinator also in the planning and programming department of the Tigray Bureau of Agriculture. She also coordinated various donor funded projects such as the UNDP funded capacity building projects. In September 2000 she joined the Agricultural Economics and Rural Policy Group of Wageningen University as Ph.D. researcher. The Ph.D. research was conducted in cooperation between Mekelle University and Wageningen University, and was financed by the Netherlands Foundation for the Advancement of Tropical Research (NWO-WOTRO). As part of her Ph.D. research she spent about three years at the Faculty of Business and Economics, Mekelle University combining field work, teaching and research. From February 2006 on she is working as Regional Financial Cooperation Consultant at the German co-financed Sustainable Utilization of Natural Resources Program for Improved Food Security in Tigray.

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