Norwegian University of Life Sciences
School of Economics and Business

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The Economic Implication of Animal Feed Scarcity on Farm Intensification, Food Production and Consumption: Empirical Evidence from Tigrai, Ethiopia

Konsekvenser av forknapphet på kvegdrift, matproduksjon og forbruk: Empirisk evidens fra Tigrai, Etiopia

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Dedication

To my Mother Lemelem Gebreazgi who sacrificed much to grow and educate her children

and

To my beloved wife Selamawit Hadush who energizes me

Acknowledgement

First of all, I would like to express my sincere thanks to the Almighty God for his love, forgiveness, and generosity and for the pray of Blessed Virgin Mary, Mother of God. Oh my God! You helped me realize my dream today! Now, with your kindness my long dream comes to reality! I do not have words to express my thanks! I honor your name, now and forever! Oh Holy Mary, Mother of God! You always hear me when I call to you!

Completing a PhD study requires strong determination, hard work and patience; needs moral, material and academic support from others; and takes a long period of time. If I have to count I consumed 20 years of schooling to reach this stage. During these long years of schooling, I have received moral, financial, and material supports from a number of individuals and institutions. In the first 13 years of my study; the entire responsibility of parenting me and financing my study was shouldered on my dad and mom. They generously invested in my education, which enabled me to enjoy life and my study at high school and Mekele University. I lack appropriate words to express my gratitude for their unreserved support without which my success in higher education would have been impossible.

Thank you my mom for your help, love, discipline, patience, and strength amidst adversity all showed me a path of fortitude. Thank you my brothers for your unique maternal affection! I owe to you! I also thank my sisters back at home for the sincere love and passion they provide me all the time. My dad, you always stay special in my memory. I cannot deny how much you invested in me for my education and has given me the chance to be where I am now but you did not live long to witness this outcome today. I dearly miss you and dedicate this thesis to you. It is very touching and painful– I cannot put a price on it!

Coming to my PhD study (2013-2017) at Norwegian University of Life Science, my heartfelt gratitude goes to my supervisor professor Stein Holden and my co-advisor Doctor Mesfin Tilahun. Their approach was so constructive and friendly so that I conducted my entire field and desk-work with full of fun. It is through their perpetual academic guidance and encouragement that I build confidence and courage to write my thesis. From the critical comments and suggestions they provided at different levels of my thesis work, I have gained ample knowledge and practical skills for conducting both academic and policy research in economic science, particularly in resource and development economics.

They also challenged me on proposal writing, theoretical model development, methodological issues and presentation styles of the findings. They helped me advance my professional skills. This thesis would not have been possible without their wise counsel, helpful comments and constant encouragement. For all the contribution they provided me in my thesis work and my academic advancement in general, I extend my sincere thanks to them and ensure to keep in touch with them in my future academic endeavor.

I gratefully acknowledge the free scholarship grant of my host institution, Norwegian University of Life Science, for giving me the opportunity to study at this esteemed university. Professor

Arild Angelsen and Professor Frode Alfnes deserve special appreciation for their active response and leadership quality they own in rational decision making. They both take a reasonable share of contribution in granting me this PhD. It gives me a great pleasure to present my sincere thanks to Vilma Bischof (Senior Adviser) for her valuable and immense administrative and academic support. I am greatly thankful for Lise Thoen (PhD coordinator) for her kind reception and cooperative whenever I need secretariat service at the department.

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During my stay in NMBU, I received a good warm company from my very good Ethiopian friends Daniel Muluworq (PhD) and Hadush Tesfa. I thank them for their nice friendship .It was those friends with whom I discuss academic matters, share ideas, and enjoy while I feel tired in my study. You will always stay special in my mind. Finally, I would like to thank the farmers of all study villages who were willing and patient in responding the lengthy questionnaire; the *Tabia* leaders that facilitated our communication with the farmers; my enumerators who exerted maximum efforts in data collection.

Muuz Hadush

Mekelle, January 2019

Table of Contents

Contents

Lists of papers

Thes thesis is based on the following four papers:

1. Paper1: Does Population Pressure Induce Farm Intensification? Empirical Evidence from Tigrai Region, Ethiopia (Muuz hadush, Stein Holden, Mesfin Tilahun) -accepted by *Agricultural economics*

2. Paper2: The Effect of Animal Feed and Water Resources Scarcity on Farm Labor and Farm Production in Northern Ethiopia (Muuz Hadush)-submitted to *Agricultural and Applied Economics*

3. Paper3: Economic Implication of Grazing and Water Resource Scarcity on Households' Welfare and Food Security in Tigrai, Ethiopia (Muuz Hadush)-published by *Agricultural and Resource Economics Review*

4. Paper4: Analyzing Production Risk and Patience on Farmers' Use and Choice of Improved Livestock Feeding Practice in Tigrai, Ethiopia? (Muuz Hadush)-submitted to *Review of Economic Development*

Summary of the Thesis

This dissertation analyses cattle farming in order to (i) test the hypotheses of Boserup and Malthus in the merits of distinguishing both direct and indirect effects of population pressure on farm intensification, and (ii) test the downward spiral hypothesis which states that people in poverty are forced to deplete resources to survive, and this environmental depletion further impoverishes them. The main dissertation is composed of 4 manuscripts. The first paper attempts to examine the effect of rising population pressure on (i) farm and herd size (ii) modern input use and (iii) farm output by applying a recursive estimation combined with a control function approach using data from 518 randomly selected farmers. The finding reveals that both Malthusian and Boserupian forces co-exist. Population pressure affected both input demand and output supply. Consistent with Malthus theory, high population pressure is found to be associated with small farm size and herd size. As predicted by Boserup's theory, the use of modern input and output supply initially increase with increasing population pressure but decline again when population densities pass a critical threshold (800 persons/km²), supporting Malthus' hypothesis.

In the second Paper, we pay specific attention to the economic effect of resource (grazing, water and crop residue) scarcity measured in a traveling time and shadow cost on labor for crop farming and crop food production. The analysis in this paper was conducted in order to test the hypothesis that increasing time spent on searching for grazing, water and collecting straw has a negative effect on crop farm labor time and crop farm production based on non-separable household model. Our results favor the hypothesis of a negative relationship between labor input to crop farming and resource scarcity. In aggregate, the findings confirm that reducing time spent looking for water and animal feed increases food production. Likewise, our results show that moderate significant difference in crop output value between male and female resulting from a resource scarcity. The quantile regression also proved that the effects of these scarce resources are heterogeneous

Paper 3 focus on the link between animal resource scarcities measured in a traveling time and shadow cost and welfare and food security drawing on a separable farm household model. The theoretical prediction that resource scarcity adversely affects household per capita food consumption expenditure (welfare) and food security, as predicted by the downward spiral hypothesis was tested using a double log IV 2SLS for the case of welfare and probit model in the case of food security. In aggregate, our principal findings confirmed that resource scarcity affect household welfare and food security adversely and effect is not uniform across the food income groups.

Paper 4 assess the effects of production risk and time preference on animal feeding practice use and feeding choice. Using the theoretical framework suggested by Antle (1987) and Koundouri et al. (2006), the author shows production risk to be the main determinants of stall feeding adoption and its full application using estimated moments of the value of milk production. It further considers discount factor and animal shock exposure into account as key factors of SF adoption and its application. Our empirical analysis revealed that production risk and time preferences are key determinant of SF adoption and full year application.

Sammendrag

Denne avhandlingen analyserer storfelandbruk i nordlige Etiopia for å i) teste hypotesene til Boserup og Malthus knyttet til hvordan befolkningspress påvirker intensivering av landbruket, og ii) den nedgående spiralhypotesen som sier at fattige er tvunget til å overforbruke de begrensede ressursene for å overleve, og dette gjør dem enda fattigere. Avhandlingen består av fire selvstendige artikler. Den første studerer virkningen av varierende befolkningspress/tetthet på i) bruksstørrelse og antall storfe pr bruk, ii) bruk av moderne innsatsfaktorer og iii) produksjon pr bruk. Analysen består av recursive regresjoner med en kontrollfunksjon tilnærming basert på et datasett bestående av 518 tilfeldig utvalgte bruk. Analysen viser at både Multhusiske og Boserupske faktorer har betydning. Befolkningspress påvirker både etterspørsel etter innsatsvarer og produksjon. Konsistent med Malthus' teori så bidrar høyt befolkningspress til mindre bruksstørrelse og flere storfe pr bruk. Som predikert av Boserup's teori øker bruken av innsatsvarer og produksjon med økende befolkningspress opp til en øvre grense for befolkningstetthet (800 personer/km^2), men avtar over dette i tråd med Malthus' teori.

I artikkel 2 studeres den økonomiske effekten av ressursknapphet (beiteareal, vann og halm fra kornproduksjon) målt i transporttid og skyggekostnader på arbeidsbehovet i planteproduksjon. Artikkelen forsøker å teste hypotesen at økende tid brukt på å skaffe fôr og vann har en negativ effekt på tid brukt i planteproduksjon og på produsert mengde. Resultatene påviser en negative sammenheng mellom ressursknapphet og arbeidsforbruk i planteproduksjon.

I artikkel 3 studeres sammenhengen mellom ressursknapphet i tilknytning til storfehold målt i form at tidsbruk og skyggekostnader og virkning på matvaresikkerhet (selvforsyning med mat). En negativ sammenheng ansees som en test av hypotesen om en negativ spiral i ressurbruk og produksjon over tid. Den økonometriske analysen indikerer at en slik sammeheng eksisterer med det er betydelig lokal variasjon mellom inntektsgrupper.

Artikkel 4 Studerer effektene av produksjonsrisiko og tidspreferanser på fôringsregimet for storfe, inklusive valg av fôrslag. Basert på det teoretiske rammeverket til Antle (1987) og Koundouri et al. (2006) vises det at produksjonsrisiko er den viktigste faktoren som fører til adopsjon av nullbeiting. Studien ser også på hvordan tidspreferanser og sjokk som direkte påvirker storfehusholdet påvirker adopsjon av nullbeiting. Det vises at også tidspreferanser har betydning for adopsjon av nullbeiting.

Introduction

1. Introduction

Globally, livestock provides animal traction to almost a quarter of the total area under crop production and traction power for about 50% of the world's farmers (Devendra, 2010a). The contribution of livestock to the world's food supply, family nutrition, incomes, employment, soil fertility and transport helps for the contribution of food security and poverty reduction (Randolph et al., 2007). Livestock also gives a safety net in the form of liquid assets and a strategy of diversification for food production (Freeman et al., 2007). Livestock is a primary livelihood source for many low-income rural farmers particularly sab-Saharan Africa (FAO, 2013). Livestock production is an important factor for smallholders to move out of poverty (see, for example, Kristjanson et al., 2007; Burke et al., 2007). A large proportion of the rural households in developing countries own livestock, which is financially valuable and plays significant social and economic roles in the communities (World Bank, 2007; Herrero et al., 2013). Livestock contributes to the livelihoods at least 70 % of Eastern Africa's rural farmers in terms of income and diet (Cecchi et al., 2010).

The contribution of livestock to food and nutritional security in developing countries is significant and serves as an important source of livelihood. At the global level, livestock products contribute 17% to kilocalorie consumption and 33% to protein consumption (Swanepoel et al., 2010). In Ethiopia, the agricultural sector is a cornerstone of the economic and social life of the people. Livestock contribution as an integral part of the agriculture accounts for 40% of total agricultural GDP, excluding the values of draft power, manure, and transport service (Asresie and Zemedu, 2015). In line to this, Yilma et al. (2011) and Beyene (2015) indicated that livestock production in Ethiopia contributes, on average, 80% of farmers' income, about 20% of agricultural GDP, about 60-71% of full-year employment and share of 16% to export.

In spite of a large cattle population, the contribution of livestock production to agriculture is below the expected level and is deteriorating (Gebremedhin et al., 2004; Ilyin, 2011). The average daily milk production in Ethiopia was only 1.69 liters with an average lactation length of about 180 days, giving a mean annual milk yield per cow of 305 liters. Likewise, the per capita milk consumption has decreased from 26 liters per annum in 1980 to 16 liters in 2009 (Yilma et al., 2011). A study conducted by Klitzing et al. (2014) in the highlands of Ethiopia showed that the performance of the sector is hampered by a low quality and quantity of feed resources and seasonal fluctuations in feed resources. Although the major feed resources are crop residues and natural pasture, their availability is gradually declining as a result of crop expansion, settlement and land degradation (Gebremedhin, 2009).

In Ethiopia, livestock production depends on natural resources such as grazing feed and water. About 10% of the cropland is used for producing crop residues used for feeding livestock and animals in the extensive system compared to the intensive system need more water per animal (Bezabih & Berhane, 2014). However, land degradation in Sub-Saharan Africa (SSA) remains a substantial problem to spur rural poverty (Bhattacharya and Innes, 2006; Tesfa & Mekuriaw, 2014) by reducing the availability of important goods and services to poor rural households and by increasing the demands on labor needed to seek for such goods in East Africa (Lal & Stewart, 2010). A recent survey in rural Ethiopia and South Africa found that feed and water shortage, labor scarcity and lack of capital were major constraints limiting livestock production where feed and water shortage were ranked first and second important constraints (Tegegne, 2012; Descheemaeker, 2008). This is mainly associated with the environmental degradation in Ethiopia. Gebreselassie et al. (2016) have estimated the cost of land degradation in Ethiopia using the total economic value approach (TEV). They found that the annual cost of land degradation related to land use and cover change in Ethiopia is estimated to be about $4.3 billion. With regard to the effect on livestock value, the total annual costs of milk and meat production losses were about $38 million and $2.4 million respectively due to land degradation in grazing lands.

The primary causes for the low livestock productivity in SSA are the low quantity and quality of feed (Benin, 2006; World Bank, 2007), the predominance of indigenous, low-yielding breeds, the inadequate availability of water resources for drinking and the prevalence of diseases, and the high rates of livestock mortality (Negassa and Jabbar, 2008). Resource depletion has contributed to the existing problem of food insecurity and is becoming a real threat to agricultural farming in Ethiopia (Bewket, 2011). Environmental problem has reached a critical stage which, poses a major threat to the agriculture production and welfare (Gebregziabher et al., 2009). In Tigrai region, one explanation for the low quality and quantity of feed is that increasing populations, resulting in high demand for arable land for food production and settlement, reducing further the size of natural grazing land (Steinfeld et al., 2006; Benin, 2006). Enclosures are also known for shrinking grazing land and grass production (Mekuria et al., 2011) despite the fact that they provide economic and ecological benefits (Babulo et al*.,* 2009).

Explorative studies (e.g. Steinfeld et al., 2006; FAO, 2010; Herrero et al., 2013; Gerber et al., 2011) at regional level propose intensification through improving feed qualities, using more productive breeds, improving management practices so as to improve livestock productivity and mitigate the detrimental effects of livestock on the environment, in particular on climate change. However, the intensification practices is often challenged by the lack of sufficient capital, land, labor, feed and water resources, or these practices and keeping fewer animals do not fit their sociocultural reality among smallholder farmers in the region (Owen et al., 2012; Herrero et al., 2015; Udo et al., 2016). Although it does not match the resources of the poorest rural households, a relatively successful intensification strategy for smallholders is improving cattle feeding practices along with the introduction of breeds or crossbreds so as to increase household income from milk and animal product sales, reduce risk exposure and feed shortage (McDermott et al., 2010; Udo et al., 2011).

The stock of literature boasts empirical studies about crop intensifications excluding livestock farming that have contributed significant knowledge about productivity enhancing technologies (Binswanger-Mkhize & Savastano, 2014; Pender et al., 2006; Muyanga & Jayne, 2014; Ricker-Gilbert et al., 2014; Headey et al., 2014; Jayne et al., 2014; Josephson et al,, 2014), have considered the effects of scarce environmental goods (fuelwood, leaf fodder, dung and grass) on agricultural production and labor input (Cooke, 1998; Damte et al., 2012; Kumar and Hotchkiss, 1988; Mekonnen et al., 2015; Mekonnen et al., 2017 ; Tangka and Jabbar, 2005), and examined the relationship between production risk and technology adoption(Juma et al., 2009; Kassie et al., 2009; Koundouri et al., 2006; Ogada et al., 2014) in the region but of potentially greater interest – and less well studied – are the effect of population pressure on cattle farm intensification (Jayne et al., 2014); the effect of environmental resource (grazing and water) scarcity on crop production and consumption (Cooke et al., 2008; Khan, 2008), and the relationship between production risk and time preference and livestock feeding practice (Liu and Huang, 2013; Just et al., 2010).

Based on these observations, this dissertation focuses on four main areas: It examines cattle farm intensification in response to population pressure based on Boserupean (1965) and Malthusian (1798) theory. It analayzes the effect of scarce resources on agricultural output, labor to crop farming, food consumption expenditure and food security by considering three important resources for an animal such as grazing, water and crop residue drawing on downward spiral hypothesis (Ostrom et al., 1999). It further attempts to distinguish the link between production risk and time preference and improved livestock feeding practices based on production risk theory (Antle, 1987; Koundouri et al., 2006).

Paper 1 examines the association of population pressure on (i) land and herd size (ii) technology use (breed cow, stall feeding and supplementary feed), and (iii) output supply (milk yield, straw, milk and crop income, off-farm job). Paper 2 examines if the time allocation to scarce resources (grazing, water and crop residue) reduces crop production by reducing labor time while paper 3 investigates the effect of these scarce resources on per capita food consumption expenditure and food security. Finally, paper 4 studies the effect of production risk and time preference on stall feeding adoption and its full application. The novel contribution of this dissertation lies in the analysis of cattle farming in order to (i) test the hypotheses of Boserup and Malthus in the merits of distinguishing both direct and indirect effects of population pressure on the cattle farm intensification, and (ii) test the downward spiral hypothesis which states that people in poverty are forced to deplete resources to survive, and this environmental depletion further impoverishes.

This broadens the empirical studies examining crop intensification in responses to population pressure. Previous studies focused on a narrow range of crop intensification excluding cattle farming intensity while livestock has an equivalent contribution to the economy of the region; (iii) test the hypothesis that increasing time spent on searching grazing, watering and collecting straw has a negative effect on crop farm production, food consumption and food security. The existing studies focus on the effect of scarce resources on labor allocation rather than focusing exclusively on the analysis based on the economic scarcity of these scarce resources on household's welfare; (iv) test the hypothesis that farmer's stall feeding adoption is motivated by the expected return of milk but discouraged by milk output variability and impatience. The explicit treatment of production risk, shock and discount rate in the decision to adoption and application distinguishes the study from previous studies which focused on crop production risk shock while excluding milk production and discount rate in the adoption decision.

The introduction chapter proceeds by providing a theoretical framework and literature review in section 2. Section 3 describes the study area and data sources. The empirical methods used to analyze papers in the dissertation are then presented in Section 4. Then, this is followed by a summary of papers and their limitations in sections 5. Section 6 finally presents conclusions and policy implications of the dissertation to the region in general and Ethiopia in particular.

2. Theoretical Framework and Literature Review

In developing countries, smallholder dairy farm provides significant potential benefit for the rural population as a source of income (Kidoido and Korir, 2015), nutrients (FAO, 2013), and employment opportunities (Beyene, 2015), opportunities to improve the livelihood options of women (Johnson et al., 2015). The development of the livestock sector is dualistic. Near peri-urban areas are growing whereas, at the same time, smallholders are still heavily dependent on traditional subsistence systems, characterized by low productivity and market access constraints (Rao et al., 2005). In response to globalization and increasing demand for animal-product based diets, rapid changes are taking place in the livestock sector of developing countries, owing primarily to the combination of population growth, increasing consumer preference and urbanization (Mpofu, 2014). The annual growth in consumption and production of animal products is 2-4% in developing countries, while developed countries have a record of 0.5% (Peden et al., 2006).

However, the overall growth in production is even far less spectacular if the transforming countries are excluded from the group of developing countries (World Bank, 2007). According to Kristjanson et al. (2007) and Burke et al. (2007), livestock production is an important factor for smallholders to move out of poverty. Livestock is quite valuable financially and plays significant social and economic roles for a large proportion of the rural households in developing countries (World Bank, 2007; Herrero et al., 2013; Mpofu, 2014). It contributes to the livelihoods of at least 70% of Eastern Africa's rural farmers in terms of income and diet (Cecchi et al., 2010). It can also lead to better nutrition and health, and to environmental preservation (Steinfeld et al., 2006). Obviously, the increase in demand for animal products also leads to an increased pressure on environmental and water resources unless adapting technologies are introduced to allow for an increase in animal productivity and curb further environmental degradation (Steinfeld et al., 2006).

2.1. Population Density and Livestock Farm Intensification

A mixed crop-livestock system is the common practice in the highlands of Ethiopian (Bezabih & Berhane, 2014; Steinfeld et al., 2006). Both activities tend to integrate more intensively with increasing population density and land scarcity (Rao et al., 2005). Population growth, urbanization, economic growth and flourishing markets all lead to the increasing demand for animal products (Costales et al., 2006; Steinfeld et al., 2006) in the region. However, continuous area expansion is becoming impossible for smallholders (Chamberlin et al., 2014), resulting in environmental damage caused by the conversion of grassland and forests to agriculture (Powlson et al., 2011). The expansion is further constrained by the market, production risks and different barriers, including limited access to land, labor and credit, subsidies and market distortions, lack of technology transfer and transaction costs (Costales et al., 2006; Steinfeld et al., 2006).

In the case of cattle farming, natural pasture and crop residues are important sources of livestock feed in most SSA (Herrero et al., 2013). The disappearance of land for crop and grazing becomes critical in the region (Headey et al., 2014; Muyanga & Jayne, 2014), resulting in low animal production and consumption. Its Importance is gradually declining because of the expansion of crop production, redistribution of communal lands to the landless and land degradation (Gebremedhin, 2009). Benin (2006) also indicated that increasing populations results in high demand for arable land for food production and settlement, reducing further the size of natural grazing land in Ethiopia. As a result, farming along the extensive margin is becoming neither viable nor optimal (Muyanga and Jayne, 2011). Increasing livestock production on account of increasing population and urbanization through the use of feeding and breeding technologies has been practiced since the last decades (Steinfeld et al., 2006). An increasing population increases demand for land for crops and livestock; forcing people onto new land.

According to the 2013 GAP report (Global Harvest Initiative, 2013), the adoption of advanced agricultural technologies and better production practices are viable options for realizing significant productivity gains in both developed and developing countries. An explorative studies conducted at regional levels (e.g. Steinfeld et al., 2006; FAO, 2010; Herrero et al., 2013; Gerber et al., 2011; Herrero et al., 2015; Udo et al., 2016) propose intensification through improving feed qualities, using more productive breeds, improving management practices so as to improve livestock productivity and mitigate the detrimental effects of livestock on the environment. Steinfeld et al. (2006) suggested that limiting the land requirements for livestock production systems through promoting intensification is warranted given the negative impact of livestock production systems on the environment. Ethiopia has a history of adopting technologies to economize on inputs or maximize value per hectare (Kirui and Franzel, 2011; World Bank, 2014).

In contrast to the low livestock productivity in SSA countries, historical intensification of the livestock sector in developed countries have led to high levels of livestock productivity (Rao et al., 2005; Steinfeld et al., 2006). In SSA, intensification of the livestock sector is nearly missing. The basis of poor adoption rates of so-called improved technologies is that smallholder farmers often lack sufficient capital, land, labor or feed resources for intensification practices, or these practices and keeping fewer animals do not fit their sociocultural reality (Owen et al., 2012; Herrero et al., 2015; Udo et al., 2016). It is also constrained by a lack of understanding and the disregard of households as primary actors and decision-makers on input use, labor allocation, the timing of operations, product marketing. Besides, agronomic problems, a land shortage for individual farms, labor shortage, and the fact that legume trees have a low multipurpose value are major constraints for intensification (Mekoya et al., 2008) as a result, research and development of new technologies can result in the required intensification in the region.

The stock of literature boasts empirical studies about crop intensifications excluding livestock farming (e.g., Binswanger-Mkhize & Savastano, 2014; Muyanga & Jayne, 2014; Ricker-Gilbert et al., 2014; Headey et al., 2014; Jayne et al., 2014; Josephson et al,, 2014), However, questions remained unexplored about the effect of population pressure on cattle farm intensification(Jayne et al., 2014). More specifically with regard to Boserup, it was hypothesized that modern input use and cattle farm output increases continuously with increasing population pressure but starts to decline again when population density pass a critical threshold, supporting Malthus ‘s view. In view of this, this dissertation draws on the current argument, initiated by Malthus and Boserup that rural farmers increase cattle productivity to feed a rising population through farm intensification, or small land and cattle size lead to economic collapse, supporting the Malthusian theory.

Boserup (1965), in contrary to Malthus's view, hypothesized that increasing population density leads to the use of modern inputs, and a shift away from extensive to intensive farming practice, which creates a theoretical and empirical link between population pressure and farm intensification (Headey et al., 2014) for this dissertation. Under the assumption of the free market, rising population density is hypothesized to influence agricultural production through three pathways; shrinking land and cattle holding sizes, increasing labor supply, and increasing demand for food (Muyanga & Jayne, 2014). From Malthus' (1798) point of view, it has been argued that population is predicted to increase exponentially while production increases arithmetically, thereby output per head declines due to declining environmental resource and diminishing returns to labor and capital. This brings scholars to conclude that population pressure does drive intensification- as hypothesized by Boserup, up to a certain point and starts to decline when the maximum carrying capacity is reached, signaling the prediction of a Malthus (Henao and Baanante,1999).

Additional theories of von Thünen (1826) and Hayami and Ruttan (1970) extend this debate by arguing that prices drive behavioral responses to adapt to changing conditions caused by population pressure. The former theory suggests that farmers switch to higher value crops, in order to maximize farm income when land prices increase (Guiling et al., 2009) while the latter theory, often termed as the induced innovation hypothesis, postulates that there is a positive association between population density and farm productivity occurring as a result of falling the price of labor relative to the price of land. This further cause demand for labor-intensive and high-yield, modern inputs use to increases, which ultimately result in an increase in production per hectare. It is also hypothesized that population pressure itself directly drive farm intensification since regions with high population density are characterized by more information flow, availability of institutions and low transportation costs (Conley and Udry, 2010). In this regard, Pingali and Binswanger (1988) added that agricultural intensification is not only driven by population growth alone, but also by access to market and innovation induced by policy in Sub-Saharan Africa.

2.2. Land Degradation and Agricultural Food Production and Consumption

Land degradation in Sub-Saharan Africa remains a substantial problem in aggravating poverty, by reducing the availability of important environmental goods and services to poor rural households and by increasing the demands on labor needed to seek for such goods (Lal & Stewart, 2010; Tesfa & Mekuriaw, 2014). Land degradation mainly caused by overgrazing and deforestation (Tesfa & Mekuriaw, 2014) adversely affect crop and livestock production by shrinking grazing and farmlands. It has been a concern for many years and is still a big threat to the future (Tesfa & Mekuriaw, 2014) in the region. According to Ilyin (2011), overgrazing cause nearly 50% of land degradation reducing the contribution from livestock and pose a threat to food security (Juma et al., 2009). World Bank (2014) reported that the cost of environmental degradation is almost 8% of GDP across countries consisting 40% of the developing countries.

The rising human population has placed huge pressure on natural resources resulting in land degradation (Bossio et al., 2007), where land degradation is closely related to the degradation of other natural resources, such as vegetation, biodiversity, grazing and water negatively affecting their productivity. About 65% of the total land surface is degraded, of which 42% is moderate to very severely degraded (FAO, 2010) in SSA. Livestock production and livestock grazing are probably the most quoted causes of land degradation (Savadogo et al., 2007), resulting in not only soil and vegetation degradation, but also pasture and rangeland degradation. Grazing and water scarcity may be less problematic in developed countries where there are available substitutes, however, the dependence on natural grazing and water implies that their scarcity can have a huge impact on household welfare in Ethiopia.

Households with scarcity may walk longer distances to search and collect these resources, thereby leaving less labor for leisure, food production and preparation (Cook et al., 2008; Bezabih & Berhane, 2014; Tegegne, 2012). The literature suggests that as a result of increasing resource scarcity such as water, grazing land and feed, many households increase the time they spend on collecting these resources (Cook et al., 2008; Damte et al., 2012). It is further suggested that water and feed scarcity, may result in lower crop productivity that further diminishes households' food supply and incomes, and hence their capacity to achieve food and nutrition security (Mekonnen et al., 2015; Tangka and Jabbar, 2005; Damte et al., 2012). The report form WOCAT (2007) suggested that along with zero-grazing practice that can release grazing pressure on pastures, watering point management, regulating traveling distances and animals' access to watering points, should be part and parcel of proactive grazing land management.

Many studies have established that the rural poor in developing countries are heavily dependent on local natural resources for their sustenance (e.g., Narain et al., 2008). Their degradation, however, hurts the poor more (Khan, 2008). The downward spiral hypothesis states that people in poverty are forced to deplete resources to survive, and this environmental degradation further impoverishes them (Ostrom et al., 1999). Land degradation leads to an increase in poverty levels consistent with the findings by Kariuki et al. (2006) and Dasgupta (2007). A study in Malawi by Bandyopadhyay et al. (2011) indicated that more time spent on scarce fuelwood collection was associated with negative welfare. Dasgupta (2007) warns that if degradation of resources is not prevented substantially, the average per capita consumption level at the world level may decline. Aggrey et al. (2010) identified the poverty-environment nexus in Uganda. They showed that deforestation and wetland degradation were positively linked with poverty.

Bhattacharya and Innes (2006) highlighted that forest degradation spurs rural poverty in Sub-Saharan Africa. The findings of Khan (2008) in Pakistan supported that environmental degradation hurts the poor more. The study of Aluko (2004) showed that deterioration in the quality of life increases with increasing environmental degradation in Niger. The conceptual framework drawn in Figure1 is intended to show the linkage among causes, costs of land degradation as well as possible integrated natural resource management measures (INRM) which finally results in ecological and economic sustainability from which this dissertation is emanated. The first box comprises major factors that cause different costs of land degradation presented in the second box. While the third box comprises consequences of resource scarcity which in its turn cause vulnerabilities presented in box four. The scarcity in box two calls individual farmers to take different economic activities provided in box three so as to ensure ecological and economic sustainability that improves welfare and enhance agricultural productivity presented in box 4.

This dissertation builds its model of farm intensification, food production and consumption based on an understanding of economic theory. Thus, our variables are those that are identified by the economic theory and we test to see if there is a causal relationship between (I) population pressure and farm intensification; (II) animal grazing and water scarcity and labor for crop farming and farm production using distance and shadow price as scarcity indicators; (III) animal grazing and water scarcity and food consumption expenditure (welfare) and food security using distance and shadow price as scarcity indicators; (IV) production risk and time preference and stall feeding adoption and application. It was also hypothesized that animal grazing and water scarcity affect households' food production and consumption negatively by taking labor away from crop farming and leisure. The motivation to adopt improved livestock feeding and full application is positively explained by the expected return and patience but negatively influenced by output variability.

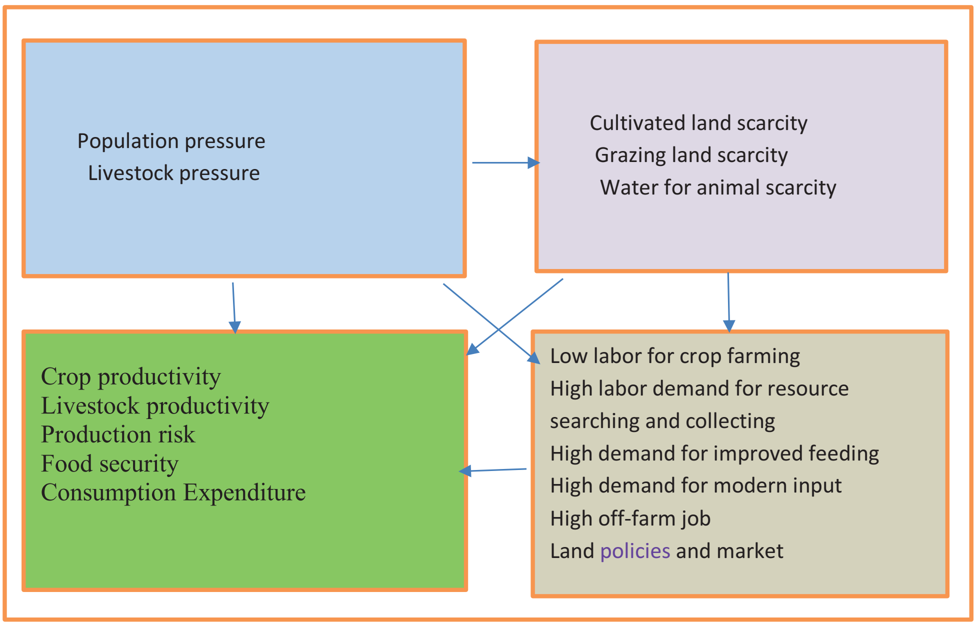

Figure 1. Conceptual Framework

The conceptual framework indicates how population pressure directly or indirectly impacts crop and dairy intensification and farm income in Northern Ethiopia: population pressure directly and negatively influences grazing and water resources as well as cultivated lands for crop farming, which makes their availability scarce for rural households. It is also possible that increasing population pressure will have an enormous negative impact on crop and livestock production, the ability of smallholder farmers to feed themselves and their families. The increase in population pressure induces a supply response where farmers adopt and intensify modern technologies to increase production of crops and livestock. It directly aggravates poverty, by reducing the availability of environmental goods such as grazing and water and by increasing the labor input needed to seek for such goods.

It is also supposed that the scarcity of land and water resource can affect household well-being either by affecting livestock production directly, affecting crop and off-farm income (via labor re-allocation) or through its direct impact on time for food preparation or leisure. An increase in population pressure also induces farmers to further intensify and adopt modern inputs in order to increase crop and livestock output given small land and cattle holdings. Improving agricultural productivity can also be achieved by improving land use policies and reducing market inefficiencies. It has been argued that agricultural intensification is not only driven by population growth alone, but also by access to market, information and innovation induced by policy in Sub-Saharan Africa. Finally, population pressure indirectly affects crop and livestock production variables through the reduction of land for crop residue and grazing lands. Poverty is not directly necessarily affected by land degradation through its impact on agricultural productivity.

3. Description of Study are and Data

The study was conducted in the Tigrai region, the northern part of Ethiopian. Ethiopia is a federal country divided into 9 regions and 2 administrative cities. Each region is subdivided into zones and zones into woredas. Woredas, in turn, are divided into Peasant Associations (PA) or *Tabias*, an administrative unit consisting of a number of smallest villages and individual households.

3.1. Study Area

Ethiopia is located in the Horn of Africa between approximately 3° 24’ to 14° 53’N latitude and 32° 42’ to 48°12’E longitude. The country covers a land area of about 1.13 million km^2. It shares boundaries to the east and southeast with Djibouti and Somalia, to the north with Eritrea, to the south with Kenya, and to the west with Sudan and South Sudan (CSA, 2008). Agriculture in Ethiopia consists primarily of small-holder farmers using low-level technology in a mixed crop-livestock farming system and is highly dependent on natural rainfall. The rainfall, in northern Ethiopia, falls in short intense events which often result in high runoff and infiltration into the soil is negatively affected by the nature of the rainfall, damaging both crops and animals by taking away the fertile soil and exposing the crop roots and animals to direct sunlight (Nyssen et al., 2005). The deteriorated soil physical characteristics further aggravate the risk of drought resulting from the lack of available soil and water (Stroosnijder and Slegers, 2008; Stroosnijder, 2009).

A mixed crop and livestock farming is the dominant livelihood system for smallholder farmers (Tesfay, 2010). Recent studies’ estimates indicate that the country has 55 million cattle, of which 55.4% are female animals (CSA, 2014). Having a favorable environment for dairy production, the country is endowed with an estimated 12 million cows (Tegegne et al., 2013; CSA, 2016), which further indicates that 2.8 billion liters of milk were produced in 2012/2013, out of which 42.3% was used for household consumption. The Ethiopian dairy sector, however, is characterized by a large gap between its actual and potential contributions to the national economy and the welfare of rural people in Ethiopia (Yilma et al., 2011). In Ethiopia, about 98.7% of the dairy cows are local breeds which partly resulting in low production and productivity of the sector. Based on national estimates, the average milk yield per cow per day for indigenous breeds is about 1.37 litres (Adane et al., 2015b) mainly constrained by the limited availability and low usage of improved dairy breeds, inputs and weak market linkages (Duncan et al., 2013; Kumar et al., 2013; Makoni et al., 2014) and low awareness of improved dairy management practices (Duguma et al., 2012; Mekonnen et al., 2010).

Livestock feed resources in Ethiopia are mainly obtained from natural and improved pastures, crop residues, forage crops, agro-industrial by-products and nonconventional feeds (CSA, 2012). The contribution of these feed resources, however, depends upon the agro-ecology, the type of crop produced, accessibility and production system (Ahmed et al., 2010). On average, one TLU requires about 25 liters of water per day and the total daily water requirement for livestock is estimated at 875 million liters amounting to about 320 billion liters per year for watering 35 million tropical livestock unit (TLU). Both human and livestock suffer from its shortage. In many parts of the country, animals have trekked to distant watering points once in two or three days since water availability for livestock is critical in the lowlands.

Most of the year, animals have to walk long distances in search of water and are usually watered once in two to three days. In many parts of the highlands, feed and water deficits start in December–January, when the natural pastures are at their lowest quantity and the supply of stored crop residues is beginning to diminish. There is usually a gap of four to five months of the dry season before the start of the short rains. The gap which lasts for about 150 days between October and March is, therefore, the critical period in a feeding and watering system that is largely based on natural grazing pasture (Sileshi et al., 2003). Although the major feed resources are crop residues and natural pasture, their availability is gradually declining as a result of crop expansion, settlement and land degradation (Gebremedhin et al., 2009). According to CSA (2010c), the total agricultural land is reported to be about 16 million ha occupied by 12.9 million households accounting for an average of 1.23 ha per household, out of the total agricultural land, 75 % is used for temporary crops while grazing land accounts for 9%.

The study region, Tigrai is located in northern Ethiopia (12° 15'N and 14° 57'N latitude and 36° 27'E and 39° 59'E longitude); it has six administrative zones with a total area of about 53,000 km^2. The total population of Tigrai is 4.3 million with an average family size of five persons per household and a growth rate of 2.5 % per year (CSA, 2008). Tigrai consists a land cover and use type of 36.2 % bush and scrublands, 28.2 % of cultivated land, 22.8 % of grassland and about 10.8 % of other land uses. The region is comprised of diverse topographic features (about 39 % Midland, 1800 – 2400 m. a. s . l.; 53 % lowland, 1400 – 1800 m. a. s. l.; and 8 % highland, 2400 – 3400 m. a. s. l.) (BFED, 2007) with mean annual rainfall ranging from 500 to 1000 mm.

Tigrai is known for its serious land degradation problem. As a result, household agricultural production is often unable to sustain families for more than 3-4 months per year (Frankenberger et al., 2007). There are about 3.24 million cattle (6.37% of the national herd) in the Tigrai region. The most important factors that determine the productivity of livestock mainly the availability of feed resources and the nutritional quality of these feeds (Tesfay, 2010).Total grazing land in Tigrai is estimated to be 47,431 km^2 while tropical livestock unit (TLU) per km^2 of grazing land was increased from 44,000 TLU in 2001/02 to 55,000 TLU in 2007/08. Thus, TLU per km2 grazing land in the region is above half for each year due to greater population density, larger herd sizes, and relatively fixed grazing land resources (Tilahun and Schmidt, 2012). In line to this, Tesfay (2010) and Gebremedhin et al. (2004) also revealed that natural grazing inTigrai is diminishing over time due to the high degree of chronic degradation and shrinking the grazing land size. Over the last decade, grassland area has been declining while the arable land area has been growing, suggesting continued conversion of grassland to croplands in the region. Animal feed in terms of quality and quantity is the major problem in the region (Abegaz et al., 2007).

Based on Tesfaye (2010), the estimated crop residues from cultivated land in the region is found to be about 1,229,651 tons dry matter/year. The region has an estimated 878,322 ha of arable land available for crop production and contributes about 45% of the animal feed demand. Felleke (2001) stated that 73% of the feed is provided from natural grazing, 14% from crop residues, only 0.2% from improved forages and the remaining 12.08% from other feed sources. According to the case study by Belay et al. (2013) which is conducted in Ethiopia, the most important problems of livestock production perceived were feed shortage (100% of respondents) and water shortage (27% of respondents) during the dry season. Livestock suffers from a seasonal shortage of feed (grazing land) and water (Descheemaeker, 2008).

Based on a recent study by Bishu (2014) in Tigrai, 34% and 7% of the respondents respectively believe that there are water and feed shortages for livestock caused by a shortage of rainfall, area closure, urbanization, high human and animal population during all seasons with critical seasonal feed shortage encountering in dry season. In the high altitude zone, livestock covers less than 1 km distance to reach water compared to the low altitude zones (Ahmed et al., 2010). Labor is another limiting factor that affects livestock productivity during the peak labor seasons for crop production activities. As a result, there is a shortage of labor for livestock management (Tegegne, 2012). Nahusenay et al. (2015) tried to examine labor allocation of family members arranged for watering and feeding and their result indicated that adult males are much more responsible for feeding animals (57%) and adult female accounts for 25% in feeding animals. Among the family members, 79% of the livestock herding activities are predominantly engaged by children.

3.2. Data Sources

The dissertation used cross-sectional data from NMBU-MU Tigrai Rural Household Survey collected in 2015 on a randomly selected 632 sample households. The study consisted of 21 *Tabias (*lowest administration unit next to district) stratified by agroecology and socio-economic indicators to get variations in population density and market access during the initial baseline. The main criteria used for stratification and sampling include ecology excluding lowlands (< 1,500 m. a. s. l.), geographical zone (Eastern, Southern, Southeastern, Central and Western) to reflect variations in rainfall and development pathways, distance to market based on far (>10KM) versus near (<10km), population density and irrigation access. Initially, to reflect systematic variation in agro-climatic conditions, agricultural potential, population density and market access conditions, four communities were selected from each of the four zones and three communities that represent irrigation projects. Likewise, one with low population density and one with high population density were strategically selected from each zone among communities to reflect far distance market (Hagos, 2003).

The initial data collection started in 1998 and continued in the years 2001, 2003, 2006, 2010 and 2015 following the same households. This implies that the data includes a panel of six rounds conducted in 1998, 2001, 2003, 2006, 2010 and 2015 where the author is involved only in collecting the data for the last round by selecting 21*Tabias* giving a sample of 632 households. The initial data collection was carried out for a random sample of 400 households in 16 villages from the specified four zones of the region (Hagos, 2003). The available panel dataset provides comprehensive household and plot level data on household characteristics, agriculture and livestock information, food consumption, rental market participation, land certificate perception as well as community-level data on GPS information including rainfall, total cultivated, irrigated and grazing area, wages, and conservation activities under safety net activities.

For this thesis, cross-sectional data for the year 2015 is extracted and organized from the survey for the empirical analysis since some variables used in this dissertation were only added in the last round of the wave. The empirical analysis of this dissertation using information regarding livestock activity further reduced the sample size to 518 farmers, those who only own livestock during the study year (82 percent of the original data, 632). Each paper in this dissertation uses a different sample size depending on the nature of the outcome variable. Paper 1 is based on 518 sample farmers while the sample size in paper2 and paper 3 drops to 509. Likewise, the sample size in paper 4 is further reduced to 360, those only milk harvesters during the survey year.

4. Empirical Method

Depending on the nature of the dependent variable, the research question and hypothesis of each paper, this dissertation uses different empirical methods relevant to each paper. Paper1 examines the effect of population pressure -total population per square arable land on (i) land and herd size (ii) technology use (breed cow, stall feeding and supplementary feed), and (iii) output supply (milk yield, straw, milk and crop income, off-farm job) drawing on the Boserupian (1965) and Malthusian (1798) theory. A recursive structural equation method based on control function (Greene, 2003; Brooks, 2008; Koutsoyiannis, 1973) has been applied in order to examine farm intensification in response to population pressure and to disentangle the direct and indirect effect that population pressure has on the outcome variables of interest. Paper 2 intends to examine if the time allocation to scarce resources (grazing, water and crop residue) reduces crop production by reducing labor time to crop farming by developing a non-separable agricultural farm household model which slightly fits into a larger family of the model developed by Strauss (1986a) and later modified by Palmer and MacGregor (2009).

The hypothesis that increasing time spent on searching water and grazing feed resources for an animal reduces labor for crop farm production, contributing to crop food production negatively was analyzed using a general Cobb-Douglas production function specification approach following Diewert (1973**)** and taking distance and shadow price as scarcity indicators as suggested by (Cooke, 1998; Baland et al., 2010; Mekonnen et al., 2015; Hadush, 2018). In order to test for separability (that is whether the labor market or straw market functions well), the relationship between the estimated shadow wage /price and market wage/price was investigated using a similar method adapted by Jacoby (1993) and Skoufias (1994). In the third manuscript (paper 3), the effect of scarce resources on agricultural food consumption expenditure and food security was examined by considering three important resources for an animal such as grazing, water and crop residue drawing on downward spiral-hypothesis (Ostrom et al., 1999). The theoretical prediction that resource scarcity adversely affects household per capita food consumption expenditure (welfare) and food security as predicted by the downward spiral-hypothesis was tested using a double log IV 2SLS for estimating welfare which enables us to address the endogeneity problem of farm income and probit model for estimating food security.

Since farm and off-farm income is not randomly distributed among rural households, this variable is likely to be endogenous (Hoddinott et al., 2008), which could be caused by omitted variables, measurement error, simultaneity or household unobservable. First, a reverse causality problem might exist, because per capita food expenditure at the household level might also influence labor productivity and thus farm productivity. Second, farm and off-farm income might be influenced by household unobservable, which can lead to a correlation with the error term. In the presence of endogeneity, the use of the OLS estimator biases the effect of income (Wooldridge, 2009). In order to avoid an endogeneity bias, the paper adopted a Two-Stage Least Square (2SLS) approach which is the most common instrumental variable estimator (Angrist and Evans, 1998) where rural farm income is instrumented by household shock experience and average rainfall of 2003-2014. This is similar to the approaches that have been used by Sarris et al. (2006); Hidalgo et al. (2010) and (Abdulai and Huffman, 2014) in different contexts.

To investigate farmers' stall feeding adoption and animal or seasonal selection decisions, the fourth paper pays special attention to the role of individual farmers' production risk, shock exposure and time preferences (Antle, 1983; Koundouri et al., 2006 and Duflo et al. 2011; Le Cotty et al., 2014). Specifically, Paper 4 focuses on production risk and time preferences by linking exogenous production risk and time preferences to farmers' decisions on: (i) adopting seasonal stall feeding practice, and (ii) choosing an animal allocated to this practice in a seasonal or full year scale. This paper uses moments of the value of milk production as a proxy for exogenous production risk, survey shock exposure and experimental methods to measure time preferences. The major empirical challenge in this paper is that time preference is suspected to be endogenous. Paper 4 tackled the potential endogeneity using control function based bivariate probit model (Wooldridge, 2010), which enables me to account for and test endogeneity bias in the case of the non-linear model when both the suspected endogenous and outcome variable are continuous.

5. Summary of Papers

The main body of the dissertation is composed of 4 manuscripts. To provide a precise and pre-review information regarding this dissertation, the summary of each paper included in the dissertation is presented in this section following guidelines of dissertation adapted by the Norwegian University of Life Science.

In the first manuscript (**Paper1**: **Does Population Pressure Induce Farm Intensification? Empirical Evidence from Tigrai Region, Ethiopia**), we attempt to answer three research questions of: (i) does rising population pressure leads to declining farm and herd size in line to Malthus's view?; (ii) do modern input use and farm output increases continuously with increasing population pressure as predicted by Boserup but starts to decline again when population pressure passes a critical threshold, supporting Malthus' hypothesis?; (iii) does population pressure has a direct effect on the outcome variables of interest and an indirect effect through its effects on landholding and inputs use? A recursive structural equation method based on control function has been applied in order to examine the effect of population pressure-total population per square arable land on (i) land and herd size (ii) technology use (breed cow, stall feeding and supplementary feed), and (iii) output supply (milk yield, milk and crop income, off-farm job) outcome variables using 518 sample size.

Although our empirical results are more in favor of the Boserupian hypothesis, the findings reveal that both Malthusian and Boserupian forces co-exist. Population pressure affected both input demand and output supply. Consistent with Malthus theory, increasing population pressure is found to be associated with shrinking farm size and herd size in the Northern highlands of Tigrai. Land degradation attributed to the heavy population pressure have caused declining and highly variable land and livestock productivity in Ethiopia and Tigrai is well known for the devastating land degradation that has resulted in a decline in agricultural productivity (Kumasi et al., 2011). As predicted by Boserup's theory, the use of breed cow, stall feeding and cattle feed, milk yield, milk income, and straw production initially increase substantially with increasing population pressure but declines again when population densities pass a critical threshold (700 persons/km^2), supporting Malthus' hypothesis. Likewise, crop farm income and off-farm job have a non-linear relation with population pressure, implying that both initially increase and then decrease with rising population pressure.

The estimation results also revealed that both milk and straw supply responded positively to their own prices. Moreover, as grazing feed resource becomes increasingly scarce, farmers react by reducing the use of breed cow and SF, thus revealing that both free grazing and SF are complementary activities. Similarly, increasing the time for feed collection induced increasing substitution of crop residue for purchased feed. Breed cow use is inversely related to the time spent on free grazing and collecting feed. The overall picture which emerges from this result is that land scarcity increases livestock farm output directly or indirectly through its effect on input use such as farmland, breed and local cow, stall feeding and supplementary feed. This has major implications for food crop production and food consumption, as it hampers farm productivity and induces farm intensification through a higher usage of modern inputs.

In the second manuscript (Paper 2*:* **The Effect of Animal Feed and Water Resources Scarcity on Farm Labor and Farm Production in Northern Ethiopia**), we pay specific attention to the measurement of the resource (grazing, water and crop residue) scarcity and their economic effect on labor for crop farming and crop food production. We noted that the evidence on the effect of natural resource scarcity (e.g., grazing, water and straw) on agricultural output is, unfortunately, sparse. The existing studies focus on the effect of these resource on labor allocation. Rather than analyzing indicators of scarcity, an analysis based on the economic scarcity of these scarce resources have on household welfare is required (Cooke et al., 2008; Khan, 2008). Therefore, the research questions that we want to answer are organized around four questions. First, what is the effect of these natural resource scarcity on crop farm labor input? Second, how does this resource scarcity affect household crop output? Third, is this effect uniform across food income groups? Fourth, is there a gender differential effect on crop farm labor input and crop output in the study region?

The analysis in this paper was conducted in order to test the hypothesis that increasing time spent on searching grazing, watering and collecting straw has a negative effect on crop farm labor time and crop farm production. At the same time, we also hypothesize the effect of these scarce resources is not uniform across the across food income groups. We also hypothesized that the negative effect is high on male farmers as compared female farmers. To address our objectives, a general Cobb-Douglas production function was estimated using a unique dataset from 518 sample farmers in Tigrai, Ethiopia. Our results favor the hypothesis of a negative relationship between labor input to crop farming and resource scarcity. In aggregate, the findings confirm that reducing time spent looking for water by 1% leads to an increase in food production by 0.16% while a one percent decrease in time wastage for searching grazing land increase food production by 0.28%. Besides, an increment of 0.33% in food production is achieved by 1% reduction in feed transporting time. In a similar fashion, the shadow price variables are significant, have the expected negative sign and are consistent with the theoretical predictions.

Likewise, our results show that moderate significant difference in crop output value between male and female resulting from a resource scarcity. The quantile regression also proved that the effects of these scarce resources are heterogeneous. Depending on results from the quantile regression, the effect of these scarce resources is not uniform across the food production distribution, imposing a high impact on the highest quantiles to low impact for the lowest quantiles of food production. In a similar fashion, the shadow price variables are significant, have the expected negative sign and are consistent with the theoretical predictions. The noble contribution of this paper is, unlike previous studies, we collected information on the entire set of crop production, along with the distance to grazing, water and crop residue of each household. Based on the empirical results presented, two areas of policy intervention can be emerged as relevant: The first involves policies that facilitate easier access to animal water tap by advocating for emergency relief. The second area of policy intervention involves the introduction of a more efficient animal feed management strategy with new livestock technologies that improve cattle production and reduce land degradation.

In the third manuscript (Paper 3: **Economic Implication of Grazing and Water Resource Scarcity on Households' Welfare and Food Security in Tigrai, Ethiopia**), we focus on the link between animal resource scarcity and welfare and food security. Poverty and resource degradation appear to go hand in hand in SSA. In Tigrai region, the environmental problem has reached a critical stage which, poses a major threat to the agriculture production and welfare (Gebregziabher et al., 2009). The critical shortage of water and feed for an animal has negative implications for agricultural production and food security in general (Mekonnen et al., 2015; Yilma et al., 2011). To our best knowledge, no study we are aware of examining the economic effect of grazing and water scarcity on per capita food consumption expenditure, which is ultimately what policy-makers seek to know (Tangka and Jabbar, 2005; Cooke et al., 2008; Khan, 2008). This is of the potentially relevant area of research but less studied.

The theoretical prediction that resource scarcity adversely affects household per capita food consumption expenditure (welfare) and food security as predicted by the downward spiral hypothesis was tested using a double log IV 2SLS for estimating welfare and probit model for estimating food security. In aggregate, our principal findings confirmed the theoretical prediction that resource scarcity affects household welfare (PCFE) and food security adversely as predicted by the downward spiral hypothesis. Our estimates show that about 48% of the households were food secure. Our results confirmed the theoretical prediction that resource scarcity affects household PCFE and food security adversely as predicted by the downward spiral hypothesis. Our results indicate that animal feed and water scarcity have an important impact on welfare and food security. As expected, in aggregate, reducing time spent searching for water by 1% leads to an increase in PCFE by 0.13% and food security by 0.059%. Similarly, a 1% decrease in time wastage for searching grazing increases PCFE and food security by 0.09%, and 0.05% respectively, and an increment of 0.07% in PCFE and 0.04% in food security is achieved by a 1% reduction in crop residue transporting time.

The total effect is simply calculated by taking the slope coefficient of income in the consumption regression multiplied by the coefficient of time allocation in the production estimation, plus the coefficient of time allocation in the consumption regression. The total impact of time spent searching for water, feed and collecting straw on per PCFE is 0.142 %, 0.102% and 0.092% respectively using distance measure. This implies that for a 1% increase in hours traveled to water, grazing and straw source PCFE decreases by 0.142%, 0.102%, and 0.092% respectively. If the median household in this data spends about 60 minutes daily to look for water and feed source and has PCFE 2490 ETB, decreasing traveling hours to a water, grazing and straw source by 0.6 minutes/day will increase PCFE by 354 (2490*0.142) ETB, 254 (2490*0.102) ETB and 229 (2490*0.092) ETB respectively for the median household.

Depending on results from the quantile regression, the effect of water and feed scarcity is not uniform across the food consumption distribution. Our paper builds on the existing literature in a number of respects. In this paper, we contribute to the literature by using a unique data to investigate how the distance to or the shadow price of water, grazing and crop residue affects PCFE and food security. We are able to estimate causal relationships with our data because, unlike previous studies, we collected information on the entire set of consumption expenditure to each household, along with the distance to grazing, water and crop residue of each household. Furthermore, unlike the previous studies, we use distance and shadow price as a proxy measure of resource scarcity.

In the fourth manuscript **(Paper 4**: **Analyzing Production Risk and Patience on Farmers' Use and Choice of Improved Livestock Feeding Practice in Tigrai, Ethiopia**?**),** we use a farmers' decision on whether to adopt stall feeding and to feed a cow in a full year scale by taking production risk, shock and discount rate into account as key factors of SF adoption and its application. We conducted both surveys and hypothetical field experimental measure of time preference in 21 administrative villages in North Ethiopia and linked the experimental measure of time preference to household investment decisions regarding the intensity of stall feeding on farm cattle. Despite their relevance, production risk, shock and time preference in the case of cattle farming are, rarely used in adoption studies in less developing countries (Liu and Huang, 2013; Just et al., 2010; Duflo et al., 2011; Le Cotty et al., 2014).

Economic theory has traditionally taken time preferences as exogenous and given. However, the author has strong theoretical grounds to suspect that discount rate is endogenous due to measurement error and market imperfection. Time preferences are not readily observed, and empirical studies have to rely on proxies. Time preference may even depend on skills in imagining and valuing the future, making it endogenous rather than exogenous (Becker end Mulligan, 1997). To address our objectives, a control function based bivariate probit model was employed (Wooldridge, 2010), which enables us to account for and test endogeneity bias in the case of a non-linear model when both the suspected endogenous and outcome variable are continuous.

In line with our suspicion, the discount rate variable was found to be endogenous, and instrumental variables for it, were statistically significant and bear the expected signs. Our empirical analysis revealed that production risk is a key determinant of SF adoption and full year application. The first moment has a highly significant positive effect on the adoption decision and full year SF application, implying that local farmers are driven by output maximization and would be encouraged to use yield enhancing practices whenever it promises them higher returns. The second moment (yield variability) showed to have a significant negative influence on the adoption probability, i.e. the higher the probability of facing extreme yield gains or losses the lower the probability of adopting SF as long as they are profit maximizers. At the same time, a higher probability of milk failure (downside risk) reduces the chance of SF adoption and full year application, indicating that SF is only attractive and applicable to the local farmer when yields are more guaranteed. This would mean that farmers could view SF as risk-increasing practice when the possibility of milk production failure is high.

Our results had further shown that frequency of previous shock exposure and time preferences are important in influencing the likelihood of adopting and applying SF practice. Impatient or present biased farmers tend to have a higher probability of adopting SF, contradicting with the previous notion that patient farmers adopt new technology but coinciding with the reality that this technology is practiced more by poor farmers with relatively less herd size and thus high discount rate. This paper is perhaps the first in East Africa and particularly in Ethiopia to capture risk using exogenous risk (production risk) from milk production function which distinguishes it from the previous literature which focused on crop production risk. Thus, the major contribution of this paper is its explicit treatment of production risk, shock and discount rate in the decision to adopt and apply SF in Northern Ethiopia.

6. General Conclusion and Policy Implications

In Ethiopia, the agricultural sector is a cornerstone of the economic and social life of the people. Rural households in developing countries heavily rely on environmental products such as fuelwood, fodder, and water to meet daily animal water and feed requirements. Land degradation in Sub-Saharan Africa remains a substantial problem in aggravating poverty, by reducing the availability of important environmental goods and services to poor rural households and by increasing the demands on labor needed to seek for such goods (Lal & Stewart, 2010, Tesfa & Mekuriaw, 2014). The increasing scarcity of grazing, water for an animal can be a significant burden to households, as grazing and water are a key factor in agricultural production in the region (Mekonnen et al., 2015).

The main objective of this dissertation was to link the animal feed and water scarcity resulting from land degradation and population pressure into animal farm intensification, food production and consumption in North Ethiopia using 518 sample farmers. We conceptualize this objective from Malthusian and Boserupian theory along with the downward spiral hypothesis. Malthus (1798) argued that population is predicted to increase exponentially, whereas production will increase arithmetically, and output per head declines due to declining environmental resources and diminishing returns from labor and capital while Boserup (1965) hypothesize that population pressure drive intensification and bring a shift away from extensive to intensive farming practice. The downward spiral hypothesis (Ostrom et al., 1999) states that people in poverty are forced to deplete resources to survive, and this environmental depletion further impoverishes them.

This dissertation also addressed issues of empirical importance, namely, the environmental and economic sustainability of cattle farming in Ethiopia while pursuing the main objective from a theoretical perspective. The environmental aspect was analyzed from a farming system perspective, comparing conventional animal feeding and improved feeding systems; the economic aspect was approached from the perspective of farm intensification of modern inputs, the productivity of milk and milk income, and .food crop production and consumption. This dissertation paid special attention to the development of methodologies that are necessary for applying the theory to empirical studies in addition to the theoretical issues.

The findings reveal that both Malthusian and Boserupian forces co-exist. Consistent with Malthus theory, high population pressure is found to be associated with small farm size and herd size. Population pressure affected both technology use (breed cow, stall feeding and modern cattle feed) and output supply (milk yield, milk and crop income, and straw output). As predicted by Boserup's theory, the use of modern input and output supply initially increase with increasing population pressure but declines again when population densities pass a critical threshold, supporting Malthus' hypothesis. The estimation results also revealed that both milk and straw supply responded positively to their own prices. Free grazing and stall feeding are found to be complementary. Moreover, farmers react by reducing the use of technology and substituting crop residue for purchased feed as grazing feed resource become scarce. This suggests that competition for scarce grazing resources is a serious threat to the livestock sector and limits further farm intensification in Ethiopia.

The empirical results favor the hypothesis of a negative relationship between labor input to crop farming and resource scarcity. In aggregate, the findings confirm that reducing time spent looking for water, grazing and straw leads to an increase in labor for crop farming and food production but the effect of these scarce resources is not uniform across the food income group. Likewise, our results confirmed that resource scarcity adversely affects household Welfare and food security in line with the downward spiral hypothesis. As expected, in aggregate, Increasing time spent searching for water, grazing and straw lead to a decrease in welfare and food security. Likewise, our results show that moderate significant difference in crop output value between male and female resulting from resource scarcity. Depending on results from the quantile regression, the effect of water and feed scarcity is not uniform across the food income group. Our result from the bivariate model revealed that the expected yield positively influenced the adoption decision and full year application while yield variability and risk of yield failure had a negative effect on the joint decision. Impatient farmers tend to adopt SF, contradicting with the previous studies but coinciding with the reality that this technology is practiced more by poor farmers.

Our result does not explain the reasons for the decrease in farming intensity beyond a certain population pressure threshold but we suspect that this is related to land degradation which is a case for further research investigation. Our study plays a great role in the understanding of the linkages between welfare, food security and environmental resources such as grazing and water scarcity. Two areas of policy intervention can be emerged as relevant. The first involves policies and institutions that facilitate easier access to animal water tap by advocating on emergency relief grounds. The second area of policy intervention involves the introduction of a more efficient animal feed management strategy that can improve cattle production and reduce land degradation. Expected benefits that the farmer can derive from low production risk due to stall feeding adoption should be included in the practice promotion agenda. This calls for timely and relevant information on the practice to be made available to livestock farmers.

Results of the bivariate regression analysis revealed that farmers facing previous frequency of livestock shocks were found to support full year application of stall feeding even during dry season than adapting free grazing system because free grazing system in the country exposes animals to contagious diseases, internal and external parasites (USAID, 2013). Farmers adopting SF protect their livestock from diseases and deaths due to cattle fighting, theft, predation, limited livestock contact and exposure to a high temperature by keeping cattle in their sheds (Bishu, 2014) and perceived production risks is lower compared to their counterparts.

The full explanation is that farmer that practice stall feeding reduces cattle contact, thereby minimizing the prevalence of diseases to mitigate the possibility of cattle loss caused by car accident, cattle fighting, predation, flood, and theft. In addition, stall feeding may mitigate the scarcity of labor by avoiding excess herding in the field and feed shortage by increasing the efficiency of feed management through haymaking and minimizing land degradation caused by free grazing systems. Full application of stall feeding seems to go parallel with reducing herd size but improving cattle breed, particularly those who have high labor time and strong social network. Considering them, therefore, can induce a faster diffusion in the country. Thus, it is important to segment the expansion of stall feeding by gender and age group.

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Paper 1

Does Population Pressure Induce Farm Intensification? Empirical Evidence from Tigrai Region, Ethiopia

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Abstract: *The scarcity of land for crop and livestock production is critical in countries with growing populations. The idea that increasing population density leads to natural resource depletion and economic failure, as predicted by Malthus, or rather to farm intensification, as hypothesized by Boserup, motivates this research. This paper examines how high population pressure in Northern Ethiopia influences smallholders' farm intensification by applying recursive estimation with a control function approach using data from 518 randomly selected farmers.*

Although our empirical results are more in favor of the Boserupian hypothesis, the findings also reveal that both Malthusian and Boserupian forces co-exist. Consistent with Malthus theory, high population pressure is found to be associated with small farm size and herd size. Population pressure affected both technology use (breed cow, stall feeding, and modern cattle feed) and output supply (milk yield, milk and crop income and straw output). As predicted by Boserup's theory, the use of modern input and output supply initially increases with increasing population pressure but declines again when population densities pass a critical threshold (700 persons/km²), supporting Malthus' hypothesis. Likewise, crop farm income and off-farm job have a non-linear relation with population pressure, implying that both initially increase and then decrease with rising population pressure.

The estimation results also reveal that both milk and straw supply responded positively to prices. Free grazing and stall feeding are found to be complementary activities. The policy implication is that rising population pressure is associated with shrinking farm size and herd size. This hampers farm productivity and thus, has major implications for food crop production and food consumption. This loss can be recovered through farm intensification but a better coordination of dairy intensification and sustainable land management is required to curve land degradation that limits further intensification.

Key words: *Recursive Model; Population Pressure; Farm intensification; Tigrai; Ethiopia.*
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1. Introduction

The contribution of livestock to the world's food supply, family nutrition, incomes, employment, soil fertility and transport helps in achieving food security and reducing poverty (Randolph et al., 2007). In rural Africa, livestock is central to human wellbeing. Livestock production plays directly and indirectly in ensuring food security and alleviating poverty (Devereux, 2014). In Ethiopia, the livestock sector contributes about 12–16% of the total GDP (Halderman, 2004), and 40% of total agricultural GDP and this does not include the values of draught power, transport and manure that livestock contribute (Asresie and Zemedu, 2015). Livestock plays a major role in food security and nutrition. Hoddinott et al. (2015) found that cow ownership increases children's milk consumption, their growth, and reduces stunting in children. Despite the contribution of the livestock sector to the livelihood of rural people and the economies in Africa, the sector is not well developed. Cattle farming in Sub Saharan Africa (SSA), for example, is heavily dependent on free grazing, which is deficient in terms of nutrition quality and quantity (USAID, 2013; IFAD, 2007). In addition, the scarcity of land for crop production and grazing becomes critical in the region (Headey et al., 2014; Muyanga & Jayne, 2014), resulting in low milk production and consumption.

Most SSA countries have also experienced rising population densities in the last decades, resulting in smaller land sizes for crop production and livestock grazing (Headey et al., 2014; Otsuka and Place, 2014). Crop farming has been based on area expansion than intensification although continuous area expansion is becoming impossible and results in environmental damage (Powlson et al., 2011; Chamberlin et al., 2014). In SSA, free grazing and crop residues are important sources of livestock feed (Herrero et al., 2013), where overgrazing becomes the primary cause of low livestock productivity and loss of resilience (Lal and Stewart, 2010). Land degradation takes the lead to adversely affect crop and livestock production by shrinking grazing and farmlands and is a big threat to the future (Tesfa & Mekuriaw, 2014).

In the Ethiopian highlands, integrated crop-livestock production is the dominant form of agricultural production. Land degradation attributed to the high population density (hereafter PD) in the country have caused declining and highly variable land and livestock productivity. Tigrai region in Northern Ethiopia is well known for the devastating effects of land degradation that has resulted in a decline in agricultural productivity (Kumasi and Asenso-Okyere, 2011). Benin (2006) indicated that increasing populations results in high demand for arable land for food production and settlement, reducing further the size of grazing land. Likewise, enclosures that are established for rehabilitating degraded lands are known for shrinking grazing land and grass production at least in the short term (Mekuria et al., 2011). As a result, farming along the extensive margin is becoming neither viable nor optimal (Muyunga and Jayne, 2011). Exploratory studies (e.g. Herrero et al., 2013; Gerber et al., 2011) propose intensification through improved feeding and breed qualities to improve livestock productivity and mitigate the environmental problem. Intensification of dairy production is widely advocated to meet the increasing demands for livestock products and to improve the livelihoods of rural households (Udo et al., 2011). This has been a relatively successful intensification strategy to increase household income (McDermott et al., 2010; Udo et al., 2011).

The empirical link between population pressure (hereafter PP) and farm intensification studied in this paper draws on Boserup's (1965) and Malthus's (1798) hypotheses. Malthus (1798) argue that population is predicted to increase exponentially, whereas production will increase arithmetically, and output per head declines due to declining environmental resources and diminishing returns from labor and capital. Likewise, Boserup (1965) claims that increasing PD leads to use of modern inputs and a shift away from extensive to intensive farming practice. A number of articles provide empirical evidence that both Malthusian and Boserupian processes co-exist in the case of crop farming (Binswanger-Mkhize & Savastano, 2017; Benin, 2006; Pender et al., 2006; Muyanga & Jayne, 2014; Ricker-Gilbert et al., 2014; Headey et al., 2014; Jayne et al., 2014; Josephson et al., 2014). These studies revealed that land productivity tends to increase up to a certain PD and gradually declines thereafter. It has been proved that some countries in SSA are able to increase crop production using modern inputs (Chamberlin et al., 2014). Jayne et al. (2014) found that PP has a positive effect on fertilizer and labor use but mixed results are found regarding the relationship between PP and farm income in SSA. Sheahan and Barrett (2017) also highlighted that the use of fertilizer input is no longer universally low but Binswanger-Mkhize and Savastano (2017) are less confident about the current state of intensification in Africa. In light of Africa's increased PD and market access, Binswanger-Mkhize and Savastano (2017) argue that higher degrees of agricultural intensification should be observed in Africa similar to Asia.

Intensification of dairy production is widely advocated to meet the increasing demands for livestock products and to improve the livelihoods of rural households (Udo et al., 2011). Ethiopia has promoted intensification to economize on inputs or maximize value per cow on account of increasing population and urbanization (Kirui and Franzel, 2011; World Bank, 2014). However, there is no empirical evidence on how PP affects dairy intensification, and far less attention was given to its implication in spite of its relevance. In the debate on intensification, the benefits are overestimated and the threshold of PP is undermined. So far, the extent to which poor people would gain from a dairy farm intensification is questionable. Thus, a better understanding that is derived from the empirical evidence is required in the region. Most studies, so far, have focused either on crop farm intensification or only on cross breed cow adoption. These studies neither have differentiated the direct and indirect effect of PP on dairy farm intensification. With this understanding, this takes us to the research questions that are rural farmers able to intensify farm production and improve their livelihoods on account of the rising population as initiated by Boserup, or will small land and cattle size lead to economic collapse, supporting the Malthusian theory?

This study sets out to explore the relevance of the Boserup (1965) and Malthus (1798) theories in investigating whether farmers are able to intensify dairy and crop farming in response to PP. We examined the effect of PP, which is measured in terms of total population per square meter of arable land, on (i) land and herd size; (ii) technology use (breed cow, stall feeding, and supplementary feed); (iii) dairy output supply (milk yield, straw and milk revenue) and (iv) crop farm income and off-farm job. We also attempted to disentangle the direct and indirect effect that PP has on the outcome variables of interest. In line with Malthus, our first hypothesis was to test that high PP leads to declining farm and herd size. With regard to Boserup, we hypothesized that modern input use and output supply increase continuously with increasing PP but both start to decline again when PD passes a critical threshold, supporting Malthus' hypothesis. We further proposed that input demand and supply output are not only driven directly by the effects of PD but also indirectly through its effects on land and inputs use. It is also possible that PD indirectly affects these outcome variables through the reduction of land for crop residue and grazing.

Our findings reveal that both Malthusian and Boserupian forces co-exist. Consistent with Malthus theory, high PP is found to be associated with declining farm and herd size. In line with a Boserupian hypothesis, our findings suggest that animal feed shortage increased stall feeding use up to roughly 700 persons/km² and declines thereafter. We also found milk output and income initially increase substantially with increasing PP up to 800 persons/ km², but both start to decline again as soon as a critical threshold of 800 persons/km² is reached, supporting Malthus' hypothesis. Likewise, crop farm income and off-farm job have a non-linear relation with PP, implying that they increase with PP up to 3645 persons/km²: beyond this threshold, rising PD is associated with a sharp decline in crop farm income and off-farm job through its negative effect on land size holding. The overall picture is that farm intensity is driven directly by the effects of PP and indirectly through its effects on input use, land and herd size in our study area.

This paper is the first to explore the relationship between PP and dairy intensification perhaps in Africa but particularly in east Africa. Although the same forces drive dairy intensification as crop intensification, it occurs autonomously. Unlike in crop intensification, farmers in dairy intensification decide to increase milk and meat yield, use labor and grazing land, innovate feeding, grow fodder, purchased extra feeds and use modern inputs such as breed cow and artificial insemination (Baltenweck et al., 2003). Thus, a separate analysis based on the empirical evidence is required in the region. The other novelty of this paper lies in distinguishing both direct and indirect effects of PD on the outcome variables within the framework of Boserup and Malthus hypotheses. Our dataset also consistently enabled us to identify the output and modern input responses to PP so that we are able to contribute to filling a key gap in the farm intensification literature.

2. Theoretical Framework

The authors set out to review and explore the relevance of the Boserup (1965) and Malthus (1798) theories in order to conceptualize how PP enters into the use of modern input and output functions. Under the assumption of the free market, rising PP is hypothesized to influence agricultural production through three pathways: shrinking land and herd sizes, increasing labor supply and increasing demand for food (Muyanga & Jayne, 2014). The theoretical and empirical link between PP and farm intensification of this paper draws on Boserup's (1965) hypothesis that increasing PP leads to use of modern inputs, and a shift away from extensive to intensive farming practice (Headey et al., 2014).

In light of Africa's PP and market access, Binswanger-Mkhize and Savastano (2017) argue that higher degrees of agricultural intensification should be observed. Malthus (1798) also argued that population is predicted to increase exponentially, whereas production will increase arithmetically, and output per head declines due to declining environmental resources and diminishing returns from labor and capital. This brings scholars to conclude that PP does drive intensification - as hypothesized by Boserup - up to a certain point and starts to decline when the maximum carrying capacity is reached, signaling the prediction of Malthus (Henao and Baanante,1999). The induced innovation hypothesis of Hayami and Ruttan (1970) also postulates that there is a positive association between PD and farm productivity occurring as a result of the falling price of labor relative to the price of land, which causes demand for labor, yield and modern inputs use to increase, ultimately resulting in an increase in production per hectare.

It is also hypothesized that PP itself directly drive farm intensification since regions with high PD are characterized by more information flow, availability of institutions and low transportation costs (Conley and Udry, 2010). To this end, Pingali and Binswanger (1988) added that farm intensification in SSA is not only driven by population growth alone. Rather it is also driven by access to market and policy-induced innovation. Based on this review in order to explore the effect of PP on farm intensification, we developed a theoretical framework that fits into a larger family of an agricultural household model (AHM) developed by Singh et al. (1986) and later modified by Huffman (1991). The full mathematical derivative of the model is given in the Appendix.

3. Study Area and Data

The study was carried out in the Tigrai region of Northern Ethiopia. Mixed crop-livestock farming is the dominant form of smallholder agriculture throughout the region. The region has rural zones: Western, Northwestern, Central, Eastern, Southeastern and Southern zone. Among these, the Eastern, Southern and Central zones are densely populated as compared to a sparsely populated Western zone reaching up to 250 persons/km^2 (Kumasi et al., 2011).

We used cross-sectional data from the NMBU-MU[2] Tigrai Rural Household Survey collected in 2015 on a randomly selected 632 sample households. The study consisted of 21 villages stratified by agroecology and socio-economic indicators to get variations on PD and market access during the initial baseline. The data we used is part of a panel of five rounds conducted in 1997/98, 2000/01, 2002/03, 2005/06 and 2014/2015. For this paper, a cross-sectional data from the 2014/2015 survey was extracted for the simple reason that some outcome and explanatory variables were only added in the last round. This study used a sample size of 518, which contains only livestock owner farmers despite the survey covered a total sample size of 632 farmers.

Fig 1 in the appendix shows that Southern zone has the highest PD followed by Central and S. Eastern zones while Eastern and N. Western zones have the median and minimum values of PD respectively. Livestock population in terms of Tropical Livestock Units (TLU) was higher for Southern and N. Western, leaving the Central zone with the lowest value of herd size (Fig 2). The

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summary of dependent variables is presented in Table 1 using descriptive statistics and results from the non-parametric estimation depicted in Fig 3 to Fig 12. Due to space limitations, only results that are highly related to the PD are presented. The remaining results for the rest of the explanatory variables are available upon request. Table 1 presents information on outcomes of interest by quantile of village PD (average number of persons per km^2) in the survey year. The findings clearly reveal that land and herd sizes are inversely related to PD (Table 1, Fig 3-4). Table 1 also shows that farmers have an average farm size of 1.6 ha in villages with the lowest quantile of PD (235 persons/km^2) and this figure declines to 0.7 ha for villages with the upper quantile of PD (1004 persons/km^2) with a median size of 1.2 ha. Evidence on declining farm size due to a high population for a number of African countries is presented in Jayne et al. (2014). Thus, farm size is much smaller in densely populated regions because farms are split among the children in the transfer of land between generations. One of its effects on livestock production is limiting access to grazing land and crop residues (Benin, 2006).

Table 1, Figures 1 to 12 here

In the case of the relation between PP and herd size, evidence from (Table 1, Fig 4) shows that the herd size in the household decreases with increasing PP. The average herd size was 4.4 TLU in villages of the lowest quantile of PD (235 persons/km^2) whereas it was 3.1 TLU for villages in the upper quantile of PD (1004 persons/km^2). The number of cows is also inversely related to the PD, falling from 2.1 cows in the villages with the lowest quantile of PD to almost 1.2 cows in villages of the upper quantile of PD. This is in line with the work that related the decrease in livestock to the loss of grazing land in densely populated regions (Hatungumukama et al., 2007). In a similar way, Benin (2006) found that availability of the share of grazing lands has declined more at higher altitudes with high PD.

We also examined the relationship between PP and the use of technologies (Table 1). The use of breed cow increases with PP up to the fourth quintile, 834 persons/km^2, and declines thereafter (Fig 6). The percentage of households practicing stall feeding is positively related to PP up to the fourth quintiles (Fig 8). The percentage of households practicing stall feeding ranges from 27 % in the most sparsely populated quintile of villages to 47% in the most densely populated villages with a median of 39%. This variation is in line with the hypothesis that increasing PD leads to use of modern inputs and a shift away from extensive to intensive farming practice (Boserup, 1965), but declines beyond these quintiles, reflecting that grazing lands in villages above 834 persons/km^2 area of farmland cannot support any further intensification, which is again in favor of Malthus' (1798) proposition. When examining the association between supplementary feed and PP, the result revealed that the use of supplementary feed was 13% in the first quartile of PP and reaches 27% in the fourth quintile. However, it decreases to less than 17% at the 5^{th} quintile (Fig 7). In line with this, Benin (2006) indicated that adoption of improved breeds and stall-feeding practices are more common in highlands than lowlands.

Finally, examining the association between PP and farm output, Fig 9-12 and Table 1 show that, up to 834 persons/km^2, milk yield varies between 1.3 liters/cow in the lowest quintile and 2.0 liters/cow in the fourth quintile and then decreases steeply to 1.6 liters/cow in the last quintile (Fig

9). In Fig 11, the daily milk revenue per cow increases from 19.5 ETB[3] to 30.6 ETB up to around 800 persons/km^2, and then declines slightly back to a value of 19 ETB. Similarly, total household straw output rises with PD up to the fourth quintile, up to 834 persons/km^2 and thereafter starts to decline. Overall rising PP reduces land and herd size directly but indirectly increases milk and straw yields. In agreement with the result of Larson et al. (2014), the inverse productivity-size relationship also holds in the case of milk production in our study region.

4. Econometric Estimation Strategy

This section presents the outline for our estimation of the effect of PD on (1) land and cattle holding; (2) technology use (breed cow, supplementary feed, stall feeding); and (3) output supply (milk yield, milk and crop income, straw harvest). Our estimation approach is close to the empirical method applied by Josephson et al. (2014). However, unlike Josephson et al. (2014) we estimated the effect of PP on dairy farming and not crop farming, and calculated the indirect effect of PP through its effect on the land and cattle size rather than the effect on land size and crop price. We also estimated the turning point beyond which the effect starts to decline or increase, and considered PP as exogenous variable (Benin, 2006; Pender et al., 2006).

Treating PD as an exogenous, we propose that PP influences these outcomes through direct and indirect pathways. PP directly influences land and cattle holdings, inputs and farm outputs. It is also possible that PD indirectly affects these outcome variables through the reduction of land for crop residue and grazing. Differentiating direct from indirect links allows us to recognize the key processes that drive dairy intensification. More precisely, the following equations are estimated:

$$L_i = \beta_l D_j + \gamma_l X_i' + \delta_l V_j' + \varepsilon_{il} \quad (9a)$$

$$I_i = \beta_k D_j + \beta_{k^2} D_j^2 + \alpha_k L_i + \gamma_k X_i' + \delta_k V_j' + \varepsilon_{ik} \quad (9b)$$

$$Y_i = \beta_s D_j + \beta_{s^2} D_j^2 + \rho_s I_s' + \alpha_s L_i + \gamma_s X_i' + \delta_s V_j' + \varepsilon_{is} \quad (9c)$$

The variables on the left-hand side are respectively farm and herd size *(L)*, a vector of three technology use, I (breed cow, stall feeding, and supplementary feed) and a vector of outcome variables, Y_i(milk yield, total milk, straw and milk revenue, crop farm income and off-farm job outputs). The household and the villages are represented by i and j respectively; D_j indicates population density (PD) for village j and β is the corresponding parameter; X_i represents a set of household characteristic variables with γ corresponding parameter while V_j represent a set of village characteristic variables used in our estimation (Table 1 to Table 5) with δ as the corresponding parameter. The subscripts l, k *and* s simply indicate the first, second and third separate recursive equations.

[3] ETB refers to Ethiopian currency where 1USD≈24 ETB during the study year, 2015

These set of equations show that they are recursive. Equation (9b) is influenced by equation (9a) while Equation (9c) is a function of both Equation (9a) and Equation (9b), indicating that PP has both a direct effect as well as an indirect effect on the outcome variables through Equation (9a) and Equation (9b). Computing the total derivative of the outcome variables with respect to PD enables us to calculate the total effect and distinguish between direct and indirect effects of PD on the input and output outcomes. More formally, the total derivative equals:

$$\frac{\partial(Y_i)}{\partial D_j} = \beta_s + 2\beta_{s^2} + \frac{\partial Y_i}{\partial L_i} * \frac{\partial L_i}{\partial D_j} + \frac{\partial Y_i}{\partial I_k} * \frac{\partial I_k}{\partial D_j} \quad (10a)$$

$$\frac{\partial(I_k)}{\partial D_j} = \beta_k + 2\beta_{k^2} + \frac{\partial I_k}{\partial L_i} * \frac{\partial L_i}{\partial D_j} \quad (10b)$$

The first and the second terms on the right side of Equations (10a and 10b) represent the direct and indirect effects of PD on output supply and input use respectively. To identify the threshold that dairy intensification occurs up to a certain critical level of PD, but decreases thereafter, it is necessary to include the square of PD in the regressions and allow for non-linear effects, implying that the total effect of PD on the outputs (10a and 10b) is not constant with increasing PD.

Assuming that the error terms are not correlated with each other, we can estimate the equations individually using OLS or probit. We estimated the set of the three Equations (9a, 9b, and 9c) independently so as to get unbiased estimates and standard errors because these equations are recursive (Greene, 2003; Brooks, 2008; Koutsoyiannis, 1973). Equation (9a) was estimated with OLS since both outcomes, land and herd size, are continuous variables. For estimating (9b), the probit model was specified since all these inputs were dichotomous outcomes by assuming all the right-hand side variables in (9b) are uncorrelated with that equation's error term. In Equation (9c), straw production, milk yield, milk and crop farm income as outcome variables were estimated using OLS and the assumption that all the right-hand side variables in (9c) are uncorrelated with that equation's error term holds true. In fact, L_i is not correlated with ε_{ik} because there is no I_i term in Equation (9a). By similar arguments to the above, Equations (9a) and (9b) do not contain Y_i, so we can use OLS on Equation (9c).

In this model among the right-hand side variables, livestock density (Ratio of cattle to farm size measured in TLU per hectare) which reflect feed scarcity is suspected to be an endogenous variable. Estimating Models $(9a, 9b, 9c)$ would result in biased estimates. Thus, a control function approach was employed to account for and test Endogeneity bias in the case of a linear and non-linear models when the suspected endogenous variable is continuous (Wooldridge, 2010). As in a two-stage IV model, the control function approach requires an instrumental variable to be used in the first stage, reduced form estimation of the livestock density. In the second stage, however, the structural equation was estimated with the observed endogenous variable and the residual obtained from the first stage as explanatory variables. The test of endogeneity is the statistical significance of the coefficient of the residual (Wooldridge, 2010) where the endogenous variable is instrumented by animal shock exposure, distance to grazing land and average rainfall of 2003-2014. The explanation is that livestock density is expected to decrease with increasing animal shock distance to grazing but increases with increasing rainfall.

5. Empirical Result

5.1. Population Pressure and Land and Cattle holdings

The first regression explains land and herd size (Table 2) as a function of PD and household characteristics. Our hypothesis was that the amount of land and herd size consistently decreases with high PD. Since the quantity of land in the study area is fixed, less land is available for each extra individual as the population grows. The direct effect of PD indicates that higher PD leads to a smaller landholding. Our result indicates that, on average, a 1% increase in the PD decreases farm size by 0.28ha in the study area in favor of Malthus' (1798) proposition and in line with the findings of studies in a number of African countries (Pender et al., 2006; Headey et al., 2014; Jayne et al., 2014; Muyanga & Jayne, 2014; Otsuka and Place, 2014).

Table 2 here

Several household characteristics also correlate significantly with land size. Landholding increases with family size, consistent with Muyanga & Jayne (2014) and Josephson et al. (2014). Besides, the age of household head and adult labor time are negatively correlated with land holding size. Farmers living in the South East and East zones had less land size than farmers living in the Southern zone, which is in line with Pender et al. (2006).

In the case of the second outcome of interest, Table 2 shows that at a low level of PD, a 1% increase of PP corresponds to a decrease of just 0.71 in tropical livestock units followed by an increase of 0.36 TLU beyond 261 persons/km², resulting in a net decline of 0.026 TLU and 0.041 cows. The findings support Malthus' (1798) hypothesis that PP leads to natural resource depletion leading to low land holdings. Regarding this, Benin (2006) indicated that increasing populations result in high demand for arable land for crop production and settlement, reducing the size of land available for natural grazing and crop residue. Besides, as expected, the ratio of closed area to households and high feed scarcity are associated with reduced animal holding.

However, the positive correlation between land size and livestock ownership is much stronger, suggesting that an extra hectare of land, on average, increases herd size by 0.33 units and ownership of cows by 0.27 units, concurring with the findings of Muyanga & Jayne (2014) and Tegebu et al. (2012). The result further indicates that farmers with farm capital and large family size are found to own more cattle and milking cows while older people with an animal shock seem to won less animal. Our result also shows that ownership of milking cows is higher and significant for female than male farmers whereas the total number of herd size declines with elevation. This is consistent with the previous study in Ethiopia (Tegebu et al., 2012). As mentioned in the methods' section, residuals from the feed scarcity reduced form estimation are incorporated in the models to control for feed scarcity endogeneity. The feed scarcity variable was found to be endogenous in these estimations, as the residuals from the first stage models were always found to be positive and statistically significant in all models.

5.2. Population Pressure and Technology Use

In this section, we present estimated results of use of stall feeding (SF), breed cows, and supplementary feed in order to understand how PD drives the intensification of these technologies (Table 3). Consistent with Boserup, we found evidence that dairy intensification seems to be an important option for adapting to small grazing lands and farmlands. The results show that smaller land size induces adoption of SF. As PD increases by 1%, adoption of SF directly increases by 24.5% and indirectly decreases by 0.5% through the effect of PD on farm size, giving a total positive effect of 21.5 % up to about 682 persons/km^2 and declines thereafter (Table 6). This provides more evidence for the existence of both Boserupian and Malthusian theory. This finding coincides with that of Headey et al. (2014) in which their finding reveals a positive relation between PD and the use of fertilizer, improved seed, pesticide, and improved feeding.

Similarly, the results show that higher household heads per km^2 of grazing land induced adoption of SF. Farmland size is also positively correlated with adopting SF. In line with the findings of Gebremdhin et al. (2003) and Martínez-García et al. (2016), our results show that higher expenditure on the salt, brewery and veterinary services discourages SF adoption. However, a higher price of local grass encourages SF adoption. A one unit rise in the ratio of milk price to the labor wage rate increases SF use by 10.4%, underscoring the crucial role played by market incentives in SF decisions. The variable representing information is positive and significant in SF adoption, and consistent with the finding of Gunte (2015).

Table 3 here

As shown in Table 3, time spent on free grazing and collecting feed has a negative effect on SF adoption since all activities compete for the same labor from the given household. A 1% increase in time to free grazing and collecting feed results in an 8.7% and 4.6% decline in the probability of adopting SF. As grazing feed resource becomes increasingly scarce, households react by reducing the use of SF, thus revealing that free grazing and SF are complementary. Highland location and farm capital use increased the probability of adopting SF by 17.9% and 12.3% respectively. This is a new result and agrees with the findings of Bishu (2014), who found that SF is more practical in the highland parts of the country using descriptive statistics.

Turning to the second technology, the probability of using breed cows increases with PD. The direct and indirect effects of PP indicated that an increase of PD increases the chance of using breed cows by 8.5%, up to a maximum of 755 persons/km^2 (Table 6). Besides, households with more land, access to information, family size, local milking cows and farm capital are more likely to use breed cows. However, breed cow use is inversely related to the time spent on free grazing and collecting feed, revealing that breed cow adoption declines with increasing the scarcity of animal feed resources. More time spent in grazing and collecting feed often leaves little time for home feeding and breeding. After controlling for its endogeneity, the feed scarcity variables is positively correlated with a breed cow use.

An increase in the ratio of milk price to median village wage also leads to a 2.4% increase in breed cow use, a result that is consistent with those result found by Baltenweck & Staal (2000) in Kenya. Farmers' modern input expenditure on livestock is both negative and statistically significant determinant of breed cow adoption. The result is in agreement with Martínez-García et al. (2016), who found a negative relation between input expenditure and improved grass adoption in Mexico.

Our results also indicate that PD has a positive effect on using supplementary feed. The direct effect of PD suggests that a 1% increase in PD increases supplementary feed use by about 20.7% up to the density of 716 persons/km^2 (Table 6). The total effect (direct + indirect effect) suggests that, on average, a 1% increase in PD increases supplementary feed use by 23%. This finding indicates that feed demand is mainly driven directly by PD and indirectly through the effect on land size.

The probability of purchasing supplementary feed decreases with increasing family and farm size, showing that farmers with more farm size and family size are less likely to purchase extra fodder. The finding that the coefficients of location and farm capital are positive and significant indicate that farmers, in highly populated areas, tend to buy extra animal feed (Pender et al., 2006). Table 3 also shows that increasing feed collecting time induces increasing substitution of crop residue for purchased feed. The variable price of grass confirms our expectation that local feed and purchased feed are substitutes. However, the input expenditure has the anticipated negative effect on the likelihood of purchasing supplementary feed. The feed scarcity variable was found to be endogenous only in the case of breed cow use, as the residuals from the first stage models is found to be negative statistically significant in that model.

5.3. Population Pressure and Output Supply

In line with this, we estimate the association between rising PD and the three output supply variables (milk, straw output and milk revenue) using OLS and results are presented in Table 4 and Table 6. We found evidence that PD is positively associated with higher milk yield. Milk yield increases with PD up to 1233 persons/km^2 and starts to increase at decreasing rate thereafter, confirming consistency with the research findings from Kenya (Muyanga & Jayne, 2014) and Ethiopia (Headey et al., 2014) in the case of crop yield. A strong positive association between milk yield and Highland location further confirms this positive effect of PD on milk yields. It makes sense that farmers living in the densely populated zone were found to initially produce more milk, supporting the findings of Adane et al. (2015) in Ethiopia.

Table 4 here

The estimation result also shows that a higher number of local milking cows and adoption of breed cows positively affect milk production. Adane et al. (2015) indicated that a higher number of lactating cows and breed cows were positively associated with higher milk output in Ethiopia. The estimated coefficient for stall feeding was positive and substantial in both total milk and milk yield models, which is consistent with the result of Turinawe et al. (2011) in Uganda. Table 4 unfolds that own price to wage ratio has a positive effect on milk yield. Though studies on the effect of own price are scanty, a study by Bhattacharya et al. (2016) in BRIC (Brazil, Russia, India and China) countries established this link. It can also be observed that the price of local feed is negatively associated with milk production.

We also present the regression result of the effect of PD on straw output in Table 4. In Ethiopian highlands, 70% of crop residues are reportedly used as animal feed (Herrero et al., 2013). Straw production is found to rise with PD up to 686 persons/km^2 and declines thereafter. An increase in PD raises straw output by about 25.2DL[4] directly and by 23.7 DL in total. This aggress with the result of Jagger & Pender (2006), who found a positive relation between crop residue and PP in Uganda. Our results also reinforce that small farm size (ratio of cattle to farm size) produce more straw output and are in line to Muyanga & Jayne (2014), implying that rising PP reduces land size directly, but increases straw output indirectly. It can also be seen that straw production responds positively to its own price, but the purchase of supplementary feed reduces the harvest of straw by 12 donkey loads.

Finally, we examine the relationship between PD and milk income per cow per day and this is found to be a linearly increasing function of PD (Table 4). An increase in PD increases milk income directly by 8.9 ETB and indirectly by 8.7 ETB through the influence of PD on breed cows, SF, land and local cow holding. Table 4 reveals that an increase of PD is associated with an increase in milk revenue up to 986 persons/km^2 but increases at a diminishing rate thereafter. The study is similar to that of Muyanga & Jayne (2014) in the case of crop income. Table 4 indicates that milk income responds positively to its own price. This corroborates with the findings of Bhattacharya et al. (2016) in BRIC countries. However, milk income responds negatively to the price of grass.

Other important factors influencing the level of household milk income include the adoption of breed cows and stall feeding as well as cattle to farm size ratio, which are in line with Turinawe et al. (2011) and Wambugu et al. (2011). The number of milking cows, the value of farm tool and Highland location also affect household milk income and the results are consistent with Adane et al. (2015) and Benin (2006) in Ethiopia. Adane et al. (2015) found that higher cost of modern feed for cows was related to more milk output. Our result is in favor of this result, revealing that higher expense on by-products induced high milk income. In line with our suspicion, the feed scarcity variable was found to be endogenous in almost all estimations, as the residuals from the first stage models were always found to be negative and statistically significant which proves the use of control function approach.

5.4. Population Pressure and Crop Farm Income and off-Farm Job

Table 5 shows interesting snapshots of the relation between PD and crop farm income and the off-farm job in the study area. Farm income has a non-linear relation with PD, implying that it increases with PD up to 3645 persons/km^2 and decrease thereafter (Table 6). The coefficient related to PD predicts that increasing PD by 1% leads to a 0.695% increase in crop farm income directly, but indirectly decreases farm income by 0.019% through its negative effect on land size. As a result, the total effect of increasing PD on farm income is 0.676%. This is in favor of the existing

[4] DL refers to donkey load which is approximately 25 KG

empirical evidence that both Malthusian and Boserupian processes co-exist in crop farming (Muyanga & Jayne, 2014; Headey et al., 2014; Jayne et al., 2014; Josephson et al., 2014).

Table 5 here

A strong negative association between farm income and elevation further reinforces the non-linear relationship of PD with farm income. This is because soil fertility is continuously declining without replenishment of sufficient amounts of nutrients in highly populated SSA areas (Meybeck and Place, 2014). Likewise, Kumasi and Asenso-Okyere (2011) suggested that land degradation reduces agricultural productivity in the highlands of Tigrai, and adversely affects the food security of smallholder farmers. The empirical result of Amare and Shiferaw (2017) indicates that nonfarm income is found to have a positive impact on farm hired labor and improved seed intensity in Ethiopia. Similarly, Nakano et al. (2018) examined the link between training and rice farm intensification and they found that trainees achieved an average yield of 4.7 tons per hectare and rice profit of 191.5 USD per hectare in Tanzania. Another result further revealed that the use of dibbling method combined with intensified weeding significantly increases farm output and net returns in Ghana (Faltermeier & Abdulai, 2009).

We find a similar pattern of results with respect to the off-farm job market as shown in column 2 of Table 5. A direct marginal effect indicates that a 1% increase in PD increases off-farm job by about 26 % on average, with an indirect negative effect of 0.027%. The total effect suggests that a 1% increase in PD is associated with a 23% increase in off-farm job participation up to PD of 3609 persons/km^2 (Table 6). However, beyond this threshold, rising PD is associated with a sharp decline in off-farm job employment. This is evidence that these poor farmers would be the most active in the off-farm job market as they are more likely to need non-farm income to survive. This finding corroborates the evidence that high PD significantly affects the likelihood of engaging in the non-farm job (Hitayezu et al., 2014). Amare and Shiferaw (2017) also indicate that nonfarm employment reduces family labor use.

Some other variables are also associated with off-farm job participation. These include larger family size, high rainfall and elevation. Households with large family size, and who, live in areas with high rainfall and elevation are more likely to have members working off the farm whereas households with large land size, longer distance to district and market are less likely to have off-farm work. This finding is consistent with other results from (Demeke and Zeller, 2012; Hitayezu et al., 2014).

6. Summary and Conclusion

The objective of this paper was to examine how the rising population in rural Ethiopia is affecting smallholder farm intensification using 518 randomly selected farmers. Farm intensification is widely advocated to improve the livelihoods of rural households but its benefits are either overestimated or undermined. Thus, a better understanding derived from empirical evidence is required. We estimated a recursive model combined with a control function approach. In line with our suspicion, the feed scarcity variable was found to be endogenous in almost all estimations, as the residuals from the first stage models were always found to be statistically significant which calls for the use of control function approach.

Our findings reveal that Malthusian and Boserupian forces co-exist. Though our result is inclined more to Boserup's hypothesis, Malthusian forces seem to be equally important. It was found that PP is a significant factor that affects modern input use and output supply. As hypothesized by Boserup, rising PD is found to be associated with shrinking farm size and herd size. This has major implications for food crop production and food consumption, as it hampers farm productivity and induces farm intensification through a higher usage of modern inputs.

When examining the relationship between PP and modern input use, the probability of adopting breed cows, stall feeding and using supplementary feed increases substantially with increasing PP at relatively low PD and declines thereafter at PD of more than 700 persons/km². Breed cows adoption declines with increasing scarcity of animal feed resources. As grazing feed resource becomes increasingly scarce, farmers react by reducing the use of breed cows and SF, thus revealing that both free grazing and SF are complementary activities. Breed cows use is inversely related to the time spent on free grazing and collecting feed. Similarly, increasing the time for feed collection induced increasing substitution of crop residue for purchased feed. The finding stated that availability of grazing lands declined more at higher altitudes with high PD so that farmers demand more additional supplementary feed.

On the supply side, we found strong support for Boserup and Malthus' hypotheses. We evidenced that PD is positively associated with higher milk yield up to 1000 persons/km² and start to increase at a decreasing rate thereafter. As expected, straw production is found to rise with PD and start to diminish at about 688 persons/km². For the rural farmers residing in areas exceeding 818 persons/km², the value of milk output declines with rising PD. The overall picture is that land scarcity increases livestock output directly or indirectly through its effect on input use and farmland. The estimation results reveal that both milk and straw supply respond positively to their own prices. The analysis also found a strong association between the price of straw and modern feed, highlighting the possibility of complementarity. Moreover, as grazing feed resource becomes scarce, farmers react by substituting crop residue for purchased feed**.**

Market milk price encourages SF and breed cow use, thus underscoring the crucial role played by market incentive in technology adoption decisions. We also found that input use and output supply are driven directly by PD and indirectly through its effects on land and herd size. Our findings suggest that competition for scarce grazing resource is a serious threat to the livestock sector and limits further dairy intensification in Ethiopia. Crop farm income shows a non-linear relation with PP, implying that it increases with PP up to 3645 persons/km² and decrease thereafter through its negative effect on land size holding. With regard to off-farm job, the total effect of PP suggests that an increase in PD is associated with a 23% increase in off-farm job participation up to 3609 persons/km².: whereas beyond this threshold, rising PD is associated with a sharp decline in off-farm job employment providing an evidence that poor farmers are active participants in the off-farm job market as they are more likely to need non-farm income to survive.

Our result does not explain the reasons for the decrease in dairy intensity beyond a certain PP threshold but we suspect that this is related to land degradation (Tittonell and Giller, 2012). An earlier study of Kumasi and Asenso-Okyere (2011) confirmed that land degradation attributed to the heavy PP have caused declining and highly variable land and livestock productivity in Ethiopia. Tigrai, the region where this study has been conducted is well known for the devastating land degradation that has resulted in a decline in crop and livestock productivity. The results of the study have at least three important policy implications. The first is that rising PD is associated with shrinking farm size and herd size. This has major implications for food crop production and food consumption, as it hampers farm productivity. Second, SF and breed cow use appear to be attractive to poor households, thus policies targeting efficient promotion and intensification of these practices are recommended. Third, the findings suggest that competition for scarce grazing resources is a serious threat to the livestock sector and limits further dairy intensification beyond a certain PP threshold in Ethiopia mainly due to land degradation. Thus, there is a need for more intervention for better coordination of dairy intensification and sustainable land management.

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Table1. Summary Statistics of Dependent Variables by Population Density Quantiles

	(First)		(Second)		(Third)		(Forth)		(Fifth)	
VARIABLES	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Farm size(ha)	1.56	0.17	1.30	0.10	1.19	0.08	1.10	0.06	0.73	0.05
Herd size(TLU)	4.37	0.31	4.27	0.35	3.81	0.29	3.81	0.22	3.10	0.23
Local cows (count)	2.12	0.14	1.94	0.13	1.62	0.11	1.49	0.06	1.20	0.05
Breed cow(Yes=1)	0.07	0.02	0.10	0. 03	0.13	0.03	0. 17	0.04	0.06	0.03
Supplementary feed (Yes=1)	0.13	0.03	0.16	0.03	0.26	0.04	0.27	0.04	0.17	0.04
Stall feeding(Yes=1)	0.27	0.04	0.35	0.04	0.39	0.05	0.47	0.05	0.31	0.05
Total milk(Littre/day)	1.91	0.12	2.43	0.21	2.95	0.28	2.91	0.22	1.98	0.24
Milk yield (Liter /cow/day)	1.29	0.07	1.66	0.11	1.93	0.10	1.98	0.09	1.61	0.13
Milk income (ETB)[a]	19.45	1.28	25.59	2.20	32.16	3.61	30.56	2.27	18.86	2.30
Fodder (donkey load)	53.30	4.45	55.44	4.31	61.28	5.68	81.32	5.34	69.70	5.50

NB: Source: own compilation, 2016: [a] 1 $USD ≈ 21 Ethiopian Birr (ETB) and words like first, second, third, fourth and fifth refer to the 1[st,] 2[nd], 3[rd,] 4[rth] and 5[th] quantile where 1[st,] =235/km2, 2[nd] =459/km2, 3[rd] =593/km2", 4[rth] =834/km2 and 5[th] =1004/km2"

Table 2. Population Pressure on Land and Herd Size

VARIABLES	(1) Farm size(ha)	(2) Herd size(TLU)	(3) Total Cows
Log(persons per Km^2 arable land)	-28.80*	-71.34*	-27.90*
	(16.15)	(40.62)	(16.59)
Log(persons per Km^2 arable land square)	14.21*	35.65*	13.74*
	(8.076)	(20.31)	(8.295)
Log(households per Km^2 grazing area)	0.089**	0.0181	-0.001
	(0.042)	(0.105)	(0.043)
Closed area to households ratio(ha)	-0.666***	-1.129***	-0.485***
	(0.121)	(0.311)	(0.127)
Ratio of cattle to farm size(TLU/ha)	-0.806***	-1.141***	-0.554***
	(0.150)	(0.386)	(0.158)
Household head age(years)	-0.038***	-0.079***	-0.037***
	(0.008)	(0.021)	(0.009)
Households' family size	0.046**	0.172***	0.012
	(0.021)	(0.052)	(0.021)
Gender of household head (1=Male)	-0.688***	-0.438	-0.651***
	(0.216)	(0.547)	(0.223)
HH head Education (Literate=1)	-0.087	-0.099	-0.143
	(0.097)	(0.243)	(0.099)
HH working adults (count)	-0.007***	-0.004	-0.005***
	(0.002)	(0.004)	(0.002)
Farm capital(cart, cattle &fodder shed=1)	1.411***	2.794***	1.181***
	(0.263)	(0.678)	(0.277)
Frequency of animal shock of 2012-2013	-0.572***	-0.807**	-0.442***
	(0.131)	(0.335)	(0.137)
Family Network (family & friends support=1)	-0.001	0.125	0.180*
	(0.103)	(0.257)	(0.105)
Location ((Highland=1)	-0.493***	-1.352***	-0.127
	(0.166)	(0.421)	(0.172)
Distance to market (walking minutes)	0.005***	0.003	0.003**
	(0.001)	(0.003)	(0.001)
Log(Distance to district in walking minutes)	-0.115*	0.176	0.0713
	(0.065)	(0.164)	(0.067)
South East	-2.063***	-3.720***	-1.774***
	(0.378)	(0.976)	(0.399)
Eastern	0.352**	0.004	-0.002
	(0.176)	(0.442)	(0.181)
North –West	-1.677***	-2.190**	-1.159***
	(0.391)	(0.999)	(0.408)
Farm size(ha)		0.334***	0.265***
		(0.113)	(0.046)
Predicted error	0.780***	1.245***	0.579***
	(0.150)	(0.386)	(0.157)
Constant	12.45***	16.05***	10.86***
	(1.831)	(4.800)	(1.960)
Observations	516	516	516
R-squared	0.205	0.332	0.290

NB: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1 indicate level of significance at 1%.5% &10% respectively

Table 3. Population Pressure on Technology Use

VARIABLES	(1) Breed Cow	(2) Stall Feeding	(3) Supplementary Feed
Log(persons per Km^2 arable land)	8.517***	24.50***	20.69***
	(3.057)	(8.140)	(5.725)
Log(persons per Km^2 arable land square)	-4.240***	-12.20***	-10.32***
	(1.527)	(4.070)	(2.862)
Log (labore hour spent on free grazing)	-0.0132*	-0.087***	0.002
	(0.008)	(0.024)	(0.017)
Log(households per Km^2 grazing area)	0.004	0.069***	0.001
	(0.006)	(0.019)	(0.014)
Log price of local grass feed (ETB)	0.013	0.082**	0.049*
	(0.013)	(0.038)	(0.027)
Ratio of milk price to village wage(ETB)	0.024**	0.104***	-0.033
	(0.009)	(0.034)	(0.043)
Log(modern animal input expenditure)	-0.031**	-0.211***	-0.097***
	(0.015)	(0.049)	(0.032)
Farm size (ha)	0.018**	0.104***	-0.088***
	(0.009)	(0.029)	(0.029)
Log Labor hour spent on home cattle feeding	0.003	0.0265	0.002
	(0.008)	(0.025)	(0.017)
Information via radio & TV (Access=1)	0.097**	0.156**	-0.013
	(0.038)	(0.063)	(0.043)
Total local milking cows	0.016**	0.016	-0.011
	(0.007)	(0.022)	(0.0175)
Household head age(years)	0.001	-0.0001	-0.001
	(0.001)	(0.002)	(0.00)
Households' family size	0.008**	0.018*	-0.015**
	(0.003)	(0.010)	(0.007)
Gender of household head (Male=1)	0.014	0.084	-0.012
	(0.017)	(0.063)	(0.047)
HH head Education (Literate=1)	-0.027*	0.025	0.045
	(0.015)	(0.049)	(0.037)
Ratio of cattle to farm size(TLU/ha)	0.016**	0.015	0.007
	(0.006)	(0.018)	(0.013)
Frequency of animal shock of 2012-2013	0.009	-0.010	-0.005
	(0.014)	(0.043)	(0.032)
Access to formal credit(Yes=1)	0.028	-0.009	0.015
	(0.024)	(0.054)	(0.040)
Location ((Highland=1)	0.098**	0.179**	0.262***
	(0.047)	(0.072)	(0.069)
Log Distance to market(walking minutes)	0.002	-0.017	0.011
	(0.011)	(0.034)	(0.025)
Log Distance to district(walking minutes)	-0.003	0.028	-0.048*
	(0.012)	(0.038)	(0.025)
Farm capital(cart, cattle & fodder shed=1)	0.046*	0.123**	0.130***
	(0.025)	(0.059)	(0.047)
Log(Time spent on transporting local feed)	-0.0135**	-0.046**	0.066***
	(0.007)	(0.023)	(0.016)
Predicted error	-0.014**	-0.013	-0.006
	(0.006)	(0.018)	(0.013)
Observations	516	516	516

NB: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1 indicate level of significance at 1%.5% &10% respectively

Table 4. Population Pressure on Supply Output

VARIABLES	(1) Straw	(2) Milk Revenue	(3) Milk Yield	(4) Total milk
Log(persons per Km^2 arable land)	2,515***	893.2***	46.04***	81.32***
	(689.7)	(288.3)	(15.59)	(26.76)
Log(persons per Km^2 arable land square)	-1,254***	-443.0***	-22.82***	-40.30***
	(344.7)	(144)	(7.793)	(13.38)
Log(households per Km^2 grazing area)	2.217	0.058	-0.069**	0.00220
	(1.539)	(0.644)	(0.035)	(0.0597)
Price of local grass feed (ETB)	8.997**	-5.348***	-0.153*	-0.429***
	(3.984)	(1.666)	(0.090)	(0.155)
Ratio of milk price to village wage(ETB)	-2.462	4.687***	0.151**	0.255**
	(3.051)	(1.275)	(0.069)	(0.118)
Log(modern animal input expenditure)	0.012	0.028***	0.001	0.00218***
	(0.017)	(0.007)	(0.002)	(0.0007)
Farm size(ha)	4.849**	0.821	0.039	0.0571
	(1.927)	(0.805)	(0.044)	(0.0748)
Supplementary feed(Yes=1)	-12.15**	0.416	-0.0284	0.0196
	(4.927)	(2.060)	(0.111)	(0.191)
Cross breed cow ((Yes=1)	12.66*	6.838**	0.295*	0.663**
	(6.899)	(2.884)	(0.156)	(0.268)
Stall feeding (Yes=1)	-2.212	3.687**	0.206**	0.344**
	(4.256)	(1.779)	(0.096)	(0.165)
Total local milking cows	1.064	5.627***	0.079*	0.521***
	(1.800)	(0.752)	(0.041)	(0.069)
HH adult labor time(hours)	0.099***	0.018	0.002**	0.001
	(0.030)	(0.013)	(0.001)	(0.001)
Log Farm tool (cart, tanker, cattle & shed)value	3.601***	1.482***	0.098***	0.143***
	(1.152)	(0.482)	(0.026)	(0.045)
Ratio of cattle to farm size(TLU/ha)	3.907***	1.201**	0.102***	0.106**
	(1.281)	(0.535)	(0.029)	(0.049)
Household head age(years)	-0.176	-0.066	-0.000133	-0.006
	(0.157)	(0.065)	(0.00354)	(0.006)
Households' family size	-0.675	0.710**	0.0455**	0.081**
	(0.856)	(0.358)	(0.0194)	(0.033)
Gender of household head (male=1)	9.198*	3.849*	0.352***	0.444**
	(5.182)	(2.166)	(0.117)	(0.201)
HH head Education (literate=1)	-1.138	-0.0560	-0.0704	-0.071
	(4.024)	(1.682)	(0.0910)	(0.156)
Location ((highland=1)	2.752	6.871***	0.513***	0.637***
	(5.499)	(2.299)	(0.124)	(0.213)
Frequency of animal shock of 2012-2014	5.658*	2.510*	0.157**	0.208
	(3.371)	(1.409)	(0.0762)	(0.131)
Predicted error	-3.127**	-0.935*	-0.0830***	-0.080
	(1.285)	(0.537)	(0.0290)	(0.049)
Constant	-10.66	-43.50***	-2.541***	-4.515***
	(29.77)	(12.45)	(0.673)	(1.155)
Observations	516	516	516	516
R-squared	0.187	0.353	0.274	0.348

NB: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1 indicate level of significance at 1%.5% &10% respectivel

Table 5. Population Pressure on Crop Farm Output and Off-farm Job

VARIABLES	(OLS) Log Farm income	(Probit) Off-Farm Job
Log(Persons per Km^2 arable land)	0.695***	0.256***
	(0.243)	(0.099)
Log(Persons per Km^2 arable land square)	-0.520***	-0.109**
	(0.123)	(0.050)
Average rainfall of 2003-2014 (mm)	-0.0491***	0.006**
	(0.006)	(0.002)
Log elevation (m)	-5.476***	0.351*
	(0.459)	(0.188)
Log cultivated land area (ha)	0.064	-0.089**
	(0.087)	(0.037)
Log manure used(Kg)	0.091*	-0.023
	(0.049)	(0.020)
Log oxen (count)	0.165	-0.024
	(0.130)	(0.053)
Log fertilizer (Kg)	0.305***	-0.015
	(0.087)	(0.035)
Log family labor (labor day)	0.452***	0.065*
	(0.083)	(0.034)
Hired Labor (Hired=1)	0.195	0.023
	(0.126)	(0.052)
Log farm tool (ETB)	0.024	-0.013
	(0.035)	(0.014)
Gender(Male=1)	-0.101	0.005
	(0.127)	(0.051)
Household head age(years)	-0.004	-0.001
	(0.004)	(0.002)
Households' family size (number)	0.051**	0.018*
	(0.025)	(0.010)
Log Distance to district (minutes)	-0.150	-0.066*
	(0.091)	(0.037)
Log Distance to market (minutes)	-0.107	-0.0778**
	(0.084)	(0.035)
HH head Education (Literate=1)	0.167	-0.0207
	(0.123)	(0.050)
Access to irrigation (Yes=1)	0.626***	0.081
	(0.132)	(0.055)
Constant	54.08***	-7.524**
	(3.693)	(3.944)
Observations	510	510
R-squared	0.503	---

NB: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1 indicate level of significance at 1%.5% &10% respectively

Table 6. Direct and Indirect Effect of Population Density on Outcome of Interest

	Effect			(25th)	(50th)	(75th)	(90th)	Turning
VARIABLES	direct	indirect	Total	q25	q50	q75	q90	point
Land size(ha)	-0.288	------	-0.288	-3.897	-14.92	-41.35*	-67.32*	-------
				(6.431)	(14.13)	(22.40)	(36.63)	
Herd size (TLU)	-0.714	-0.096	-0.809	-66.97**	-21.24	-80.99	-35.87	261p/km2
				(30.35)	(33.25)	(58.97)	(100.7)	
Total cows (count)	-0.279	-0.076	-0.355	0.000**	-0.000**	-36.13	-89.55***	_____
				(0.157)	(14.11)	(29.43)	(34.60)	
Straw (DL)	25.150	-1.396	23.753	2,033***	2,631***	1,762	2,847*	686p/km2
				(475.7)	(726.6)	(1,288)	(1,677)	
Milk Revenue(ETB)	8.932	-0.234	8.697	581.9**	775.4***	915.4***	314.1	986p/km2
				(238.8)	(299.4)	(205.5)	(738.7)	
Milk yield(L/cow)	0. 460	0. 036	0. 496	41.95**	58.94***	40.93**	-1.330	1233p/km2
				(18.02)	(17.35)	(19.23)	(78.38)	
Total milk(L/day)	0.813	-0. 017	0. 796	66.77***	71.90**	82.56***	-81.64	1134p/km2
				(23.02)	(29.23)	(19.12)	(109.5)	
Farm Income (ETB)	0.6950	-0.0192	0.6757					3645/km2
Off -farm Job(1/0)	0.2560	-0.0268	0.2292					3609/km2
Breed cow(1/0)	0.085	-0. 005	0. 079		-	-	-	755p/km2
					-	-	--	
Stall feeding(1/0)	0. 245	-0. 029	0. 215		-	-	-	682p/km2
					-	-	-	
Supplementary(1/0)	0. 206	0. 025	0. 232		-	-	-	716p/km2
					-	-	-	

NB: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1 indicate level of significance at 1%.5% &10% respectively

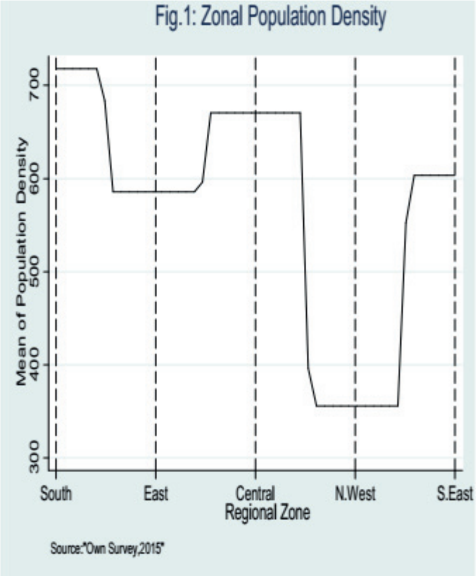
Fig.1: Zonal Population Density
Mean of Population Density
300
400
500
600
700
South
East
Central
N.West
S.East
Regional Zone
Source:"Own Survey,2015"

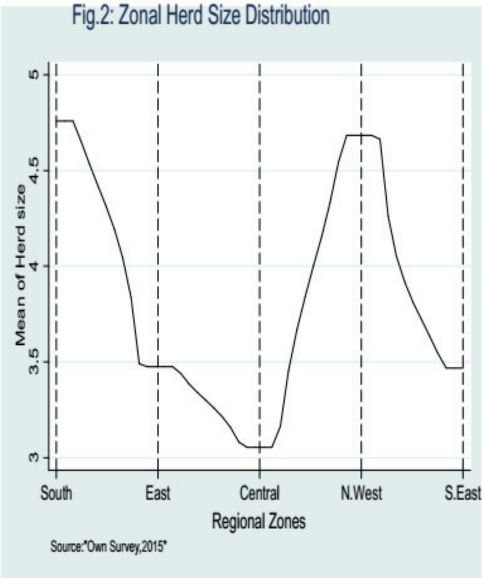
Fig.2: Zonal Herd Size Distribution
Mean of Herd size
3
3.5
4
4.5
5
South
East
Central
N.West
S.East
Regional Zones
Source:"Own Survey,2015"

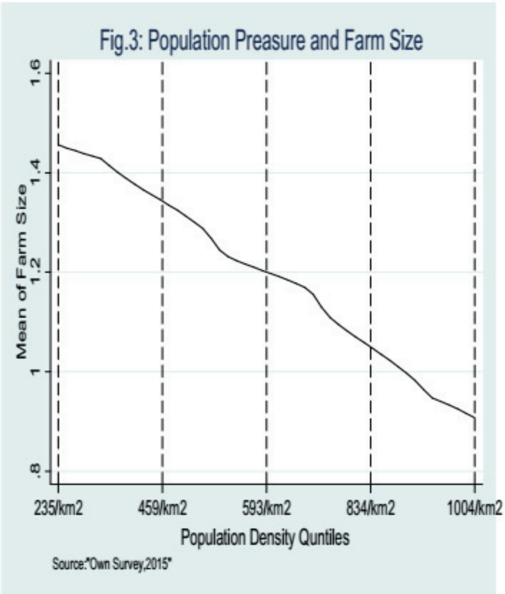
Fig.3: Population Preasure and Farm Size
Mean of Farm Size
.8
1
1.2
1.4
1.6
235/km2
459/km2
593/km2
834/km2
1004/km2
Population Density Quntiles
Source:"Own Survey,2015"


Fig.4: Population Preasure and Herd Size
3
3.5
4
4.5
235/km2
459/km2
593/km2
834/km2
1004/km2
Population Density Quintiles
Source:"Own Survey, 2015"

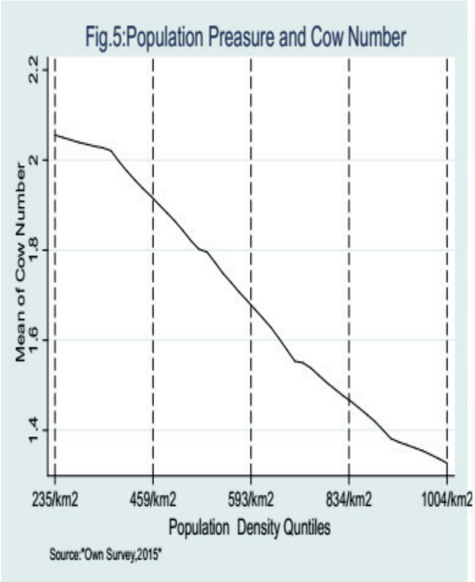
Fig.5:Population Preasure and Cow Number
Mean of Cow Number
2.2
2
1.8
1.6
1.4
235/km2
459/km2
593/km2
834/km2
1004/km2
Population Density Quntiles
Source:"Own Survey,2015"

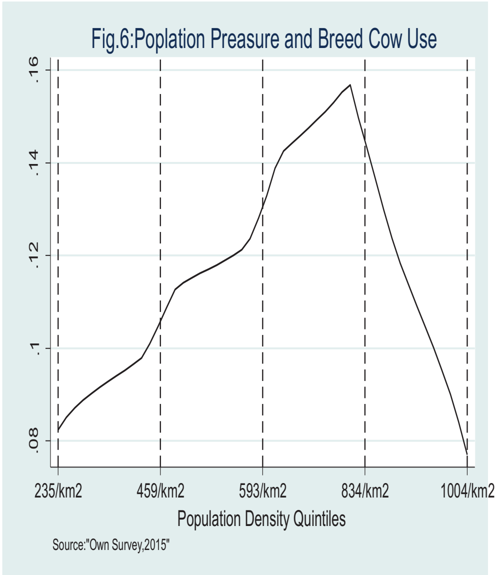
Fig.6:Poplation Preasure and Breed Cow Use
.16
.14
.12
.1
.08
235/km2
459/km2
593/km2
834/km2
1004/km2
Population Density Quintiles
Source:"Own Survey,2015"

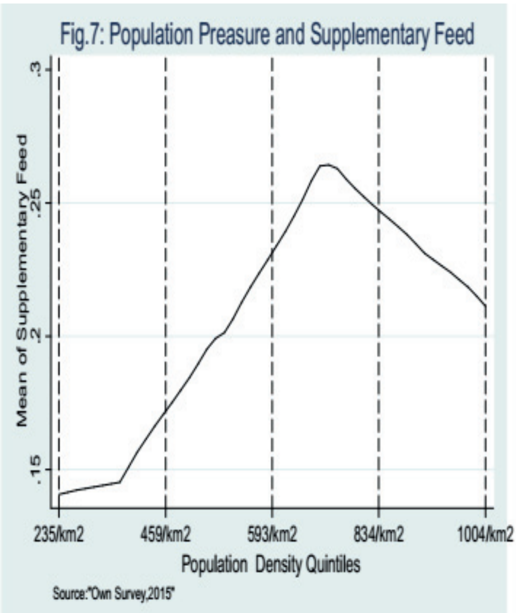
Fig.7: Population Preasure and Supplementary Feed
Mean of Supplementary Feed
.3
.25
.2
.15
235/km2
459/km2
593/km2
834/km2
1004/km2
Population Density Quiintiles
Source:"Own Survey,2015"

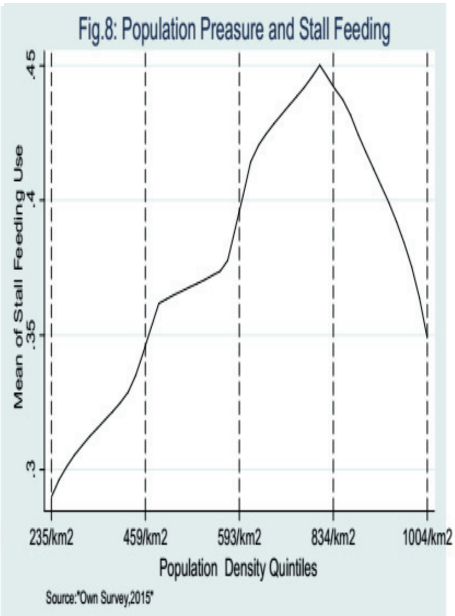
Fig.8: Population Preasure and Stall Feeding
Mean of Stall Feeding Use
.45
.4
.35
.3
235/km2
459/km2
593/km2
834/km2
1004/km2
Population Density Quintiles
Source:"Own Survey,2015"

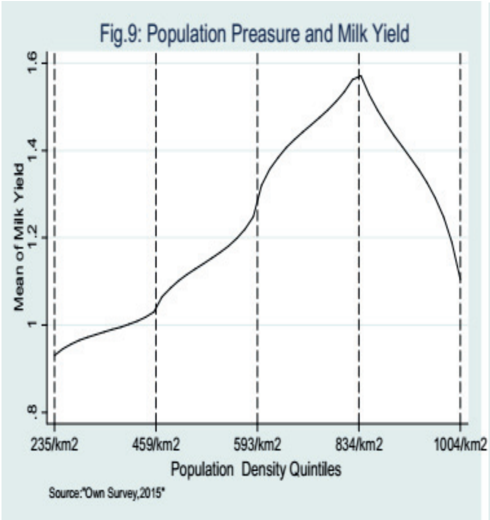

Fig.9: Population Preasure and Milk Yield
Mean of Milk Yield
.8
1
1.2
1.4
1.6
235/km2
459/km2
593/km2
834/km2
1004/km2
Population Density Quintiles
Source:"Own Survey,2015"

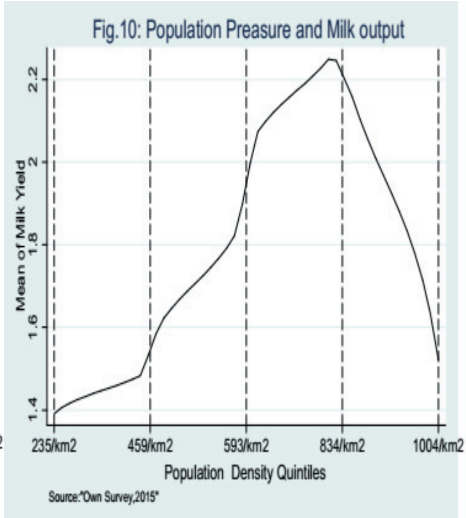

Fig.10: Population Preasure and Milk output
Mean of Milk Yield
1.4
1.6
1.8
2
2.2
235/km2
459/km2
593/km2
834/km2
1004/km2
Population Density Quintiles
Source:"Own Survey,2015"

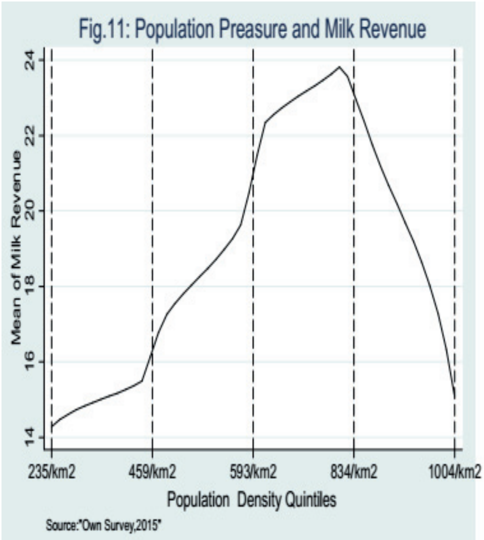

Fig.11: Population Preasure and Milk Revenue
Mean of Milk Revenue
14
16
18
20
22
24
235/km2
459/km2
593/km2
834/km2
1004/km2
Population Density Quintiles
Source:"Own Survey,2015"

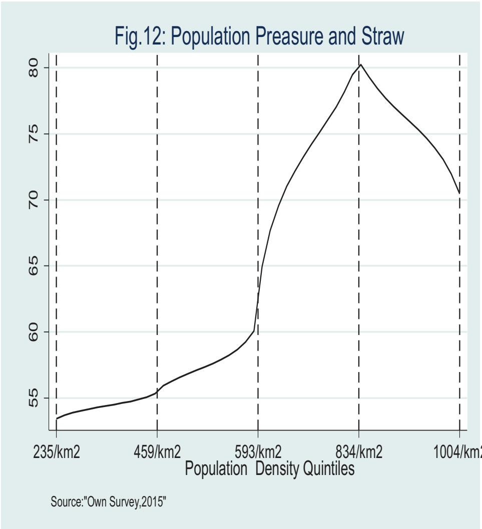

Fig.12: Population Preasure and Straw
55
60
65
70
75
80
235/km2
459/km2
593/km2
834/km2
1004/km2
Population Density Quintiles
Source:"Own Survey,2015"

Appendix

Integrated crop-livestock production is an important economic activity that promotes and sustains people's livelihoods in many developing countries (Herrero et al., 2010). In mixed crop-livestock farming systems, farmers use crop residue as a key source of livestock feeding. Likewise, manure and traction power are important outputs from livestock production to crop production. Crop-livestock intensification may take place as a result of increasing land scarcity and reduced availability of areas for grazing. New technologies such as improved breeds and crops may also facilitate such intensification. Labor is an important input in such production systems and livestock intensification may require higher inputs of labor per unit of land. Improved market access and new technologies may, however, protect or enhance the marginal returns to labor. Increasing population pressure (PP) and shrinking farm sizes in many developing countries contribute to land use intensification and there is a need to develop and adopt more resilient, intensive and sustainable mixed crop-livestock production systems to cope up with this pressure and meet the rising demands for food and feed (Kassam et al., 2010).

In this section, we try to distinguish between traditional farmers who uses a lower productivity technology and those who adopt improved technology that generates higher payoffs or yields using a theoretical framework which fits into a larger family of Agricultural household model (AHM) developed by Singh et al. (1986) and later modified by Huffman (1991). For simplicity, the household is assumed to derive utility from the consumption of own goods X_o(meals prepared from own crop grain such as wheat and animal good such as milk and meat etc.); and other purchased goods (X_m). The household utility is affected by a vector of exogenous household characteristics (Ψ), such as human capital, age, and household size and village characteristics including rainfall and agro ecology location that condition household consumption decisions.

$$U= U(X_o, X_m; \Psi) \quad (1)$$

Households maximize their utility function subject to a set of production, budget, and time constraints. Household goods X_o are produced with inputs i.e. fuel straw, E_f, which is mostly collected from communal land and labor, L_m. This household good, say for example meal for the household, is assumed to be prepared with own produced grain, A_c and animal goods, A_a. The production of household goods is also influenced by the vector of household characteristics ϕ pertaining to consumption such as the type of house, stove technology etc. The production constraints for the meal production can be described as

$$X_o = X_o\left(L_m, E_f, A_c, A_a; \phi\right) \quad (2)$$

Crop-related goods q_c, are produced using household labor, L_c. The production also depends on the amount of land, $A(S)$, livestock holdings, N, that generates inputs such as manure to enhance productivity. The PP (S) reduces the availability of A in the farm production directly and indirectly by reducing the share of land allocated to each farm household (Muyanga & Jayne, 2014) so that the PP (S) should be incorporated into the production technology explicitly or implicitly as a shifter of the production function. Households may purchase crop product, q_c at a price P_c to produce meal and yet some households also sell crop products at the same price. The household allocates family labor for crop production. It also produces crop residues in the same fields as its food crops. This production can be described as;

$$q_c = q_c(L_c, \check{S}, A(S), N) \quad (3a)$$

The animal good, q_a can be produced in both traditional and modern farms($q_a = q_b + q_t$): The household modern farm, q_b, is a function of labor (L_b), allocated animal (θ) and straw fodder Q_s mixed with the residual brew, salt and, by-products and capital (K) given the total stock of animal (D). Livestock also contributes to agricultural production by providing manure used as yield enhancing input. Q_s, the share of the total household straw or grass production (Q) is allocated to q_b and Q_t, to q_t. A household may buy and sell animal farm products produced from both traditional and modern farms at the price, P_a. Households in modern farming may buy an amount of fodder in case Q_s falls short of fodder supply given that ($Q_s - Q \geq 0$) at price P_Q in a local market or may produce by themselves in the same fields with their food crops but may not have extra surplus feed for sale. This farm is conditional on a vector of household and village characteristics, Γ, (i.e., gender, education, access to credit, the distance between house to cropland and grazing land, rainfall, agroecology location, PP etc.). Hence, the modern farm production constraint is represented by:

$$q_b = q_b(L_b, \check{S}, \theta, K, Q_s; \Gamma, D) \quad (3b)$$

In the traditional farm, q_t is a function of labor (L_t), allocated animal ($1-\theta$)from the given animal stock (D), straw fodder Q_t. A household in this farming system may not need to purchase extra feed but may sell extra fodder in case there is fodder surplus given that ($Q - Q_t \geq 0$) in the market at price,P_Q. Its equation looks like:

$$q_t = q_t(L_t, \check{S}, 1-\theta, Q_t; \Gamma, D) \quad (3c)$$

Households do not only harvest improved animal fodder (Q_s) from private land (A) in the form of crop reside but also from the stock of communal land and closed area (A_o) in the form of dry and green grass. For many households, crop residue is the primary source of animal feed in the country. The modern fodder production(Q_s), is complemented by modern inputs such as residual brew, salt and, by-products purchased (Q_f) at a price of P_f from the local market although the supply is limited. But its purchase is constrained by the total of household profit from the sale of surplus food crops and animal goods, sale of traditional fodder and off-farm wage, plus exogenous household income. The technology constraint for modern fodder production is produced by combining these inputs with household labor, L_s

$$Q_s = Q_s(L_s, A, \check{S}, Q_f; A_o, \Lambda) \quad (4a)$$

Whereas the traditional fodder production,(Q_t) mainly depends on labor, L_h, private land (A) and from the stock of communal land and closed area,(A_o) conditional on a vector of household and village characteristics, Λ. This production can be described as;

$Q_t = Q_t(L_h, A, \tilde{S}; A_o, \Lambda)$ (4b)

Farmers maximize their utility function subject to a set of budget and time constraints. Excluding leisure time in the model for the sack of simplicity, farmers' time constraint is given by

$$L_T = L_m + L_c + L_b + L_t + L_s + L_h \quad (5)$$

Farmers may have an exogenous income (E) obtained from networked relatives or safety net which enables them to overcome the cash constraints that impede their investment decision. Thus, the budget constraint in the left -hand side is expressed as the market value of crop surplus $P_c(q_c - A_c)$ and animal product surplus$P_a(q_a - A_a)$, straw or grass sale, $P_Q Q_t$ plus off-farm wage (W) in the case of surplus time endowment plus exogenous income E spent on other consumer goods, $P_m X_m$, purchase of modern feed input, $P_f Q_f$, and straw feed, $P_Q Q_s$

$$P_c(q_c - A_c) + P_a(q_a - A_a) + P_Q Q_t + W(L_T - L_m - L_c - L_b - L_t - L_s - L_h) + E = P_Q Q_s + P_m X_m + P_f Q_f \quad (6)$$

The variables P_c, P_a, P_Q,P_m and P_f refer to the market price of the crop, animal product, straw or grass, other goods and extra feed. Thus, the objective of the subsistence farm household is to maximize utility function 1 subject to (a) production constraints 2- 4 (b) time constraints 5 (c) budget constraints 6. The Lagrangian for an internal solution to the problem is set by substituting the production functions and time constraints into the budget constraint or into the utility function:

$$Ł= U\{X_m, X_o(L_m, E_f, A_c, A_a; \phi); \Psi\} + \lambda\{P_c[q_c(L_c, \tilde{S}, A(S), N) - A_c] + P_a[q_a[q_b(L_b, \theta, K, \tilde{S}, Q_s(\cdot); \Gamma, D) + q_t(L_t, \tilde{S}, 1-\theta, Q_t(\cdot); \Gamma, D)] - A_a] + W(L_T - L_m - L_c - L_b - L_t - L_s - L_h) + E + P_Q Q_t - P_Q Q_s - P_m X_m - P_f Q_f\} - \eta[(Q_s - Q) + (Q - Q_t)] \quad (7)$$

Assuming an interior solution for the choice variables such as $Q_s, Q_t, \theta, Q_f, q_t, q_t, X_m$and all labor inputs, the first-order conditions may be derived and solved simultaneously for a set of reduced-form demand equations.

$$\frac{\partial Ł}{\partial L_c} = \lambda P_c \frac{\partial q_c(\cdot)}{\partial L_c} - \lambda W = 0 \quad (7a)$$

$$\frac{\partial Ł}{\partial L_b} = \lambda P_a \frac{\partial q_a}{\partial q_b}\frac{\partial q_b(\cdot)}{\partial L_b} - \lambda W = 0 \quad (7b)$$

$$\frac{\partial Ł}{\partial L_t} = \lambda P_a \frac{\partial q_a}{\partial q_t}\frac{\partial q_t(\cdot)}{\partial L_t} - \lambda W = 0 \quad (7c)$$

$$\frac{\partial Ł}{\partial L_s} = \lambda P_a \left(\frac{\partial q_a}{\partial q_b}\frac{q_b(\cdot)}{\partial Q_s}\frac{\partial Q_s(.)}{\partial L_s}\right) - \lambda W = 0 \quad (7d)$$

$$\frac{\partial Ł}{\partial L_h} = \lambda P_a \left(\frac{\partial q_a}{\partial q_t}\frac{q_t(\cdot)}{\partial Q_t}\frac{\partial Q_t(.)}{\partial L_h}\right) - \lambda W = 0 \quad (7e)$$

$$\frac{\partial Ł}{\partial L_m} = \frac{\partial U}{\partial X_o}\frac{\partial X_o}{\partial L_m} - \lambda W = 0 \quad (7f)$$

$$\frac{\partial Ł}{\partial Q_s} = \lambda P_a \left(\frac{\partial q_a}{\partial q_b}\frac{q_b(\cdot)}{\partial Q_s}\right) - \lambda P_Q - \eta = 0 \quad (7g)$$

$$\frac{\partial Ł}{\partial Q_t} = \lambda P_a \left(\frac{\partial q_a}{\partial q_t}\frac{q_t(\cdot)}{\partial Q_t}\right) + \eta + \lambda P_Q = 0 \quad (7h)$$

$$\frac{\partial Ł}{\partial Q_f} = \lambda P_a \left(\frac{\partial q_a}{\partial q_b}\frac{\partial q_b}{\partial Q_s}\frac{\partial Q_s(.)}{\partial Q_f}\right) - \lambda P_f \leq 0 \tag{7i}$$

$$\frac{\partial Ł}{\partial \theta} = \lambda P_a \left(\frac{\partial q_a}{\partial q_b}\frac{\partial q_b(\cdot)}{\partial \theta} - \frac{\partial q_a}{\partial q_t}\frac{\partial q_t(\cdot)}{\partial \theta}\right) \leq 0; \theta \geq 0 \tag{7j}$$

$$\frac{\partial Ł}{\partial q_b} = \lambda P_a \frac{\partial q_a}{\partial q_b} = 0 \tag{7k}$$

$$\frac{\partial Ł}{\partial q_t} = \lambda P_a \frac{\partial q_a}{\partial q_t} = 0 \tag{7l}$$

$$\frac{\partial Ł}{\partial X_m} = \frac{\partial U}{\partial X_m} - \gamma P_m = 0 \tag{7m}$$

Equations (7a-7f) show how the household allocates it's time for crop farming, modern and traditional cattle farming, modern and traditional fodder collection, and meal activity. Equations (7a-7f) stated that the conditions for optimal labor allocation by the farm household is determined by equalizing the ratios of the marginal products of various activities with the relevant price ratios. Equations (7a–7e) stated that household allocates labor for various farm activities until the value of marginal product of labor used in farm activities equals the cost of household labor while equation (7f) indicated labor is used for meal preparation until its marginal utility is equal to its market wage rate. Equations (7g–7h) indicated that households equate the value of marginal product of modern and traditional fodder to their market prices. The marginal product of modern and local farm to total cattle farm is given by the price of the farm output in Equations (7k–7l). However, looking into equations (7i) and (7j), the solution of the optimization problem consists of two related decisions: the decision regarding whether or not to produce modern fodder $(Q_s)$and the decision regarding whether or not to use modern animal farming (q_b).

Given that the optimal solution in equation (7i) holds with equality, households will produce Q_s with the extra input (Q_f) and the household will equate the marginal value of the purchased input to its price. Thus, the decision to buy extra feed occurs when its market price, P_f is either smaller than or equal to its left-hand side value of (7i). If the right-hand side of (7i) that is the cost of the input exceeds its marginal value, the household will be unwilling to produce,Q_s, and thereby farmers will choose to produce under (q_t) using (Q_t). This is true when the optimal solution in (7i) holds with inequality. The two sequential decisions whether to use input Q_f or not and to produce animal product under q_b reveal that the optimal solution in equation (7j) is conditional on the optimal solution in equation (7i). This implies that the optimal solution in (7j) holds with inequality when the optimal solution in equation (7i) also holds with inequality indicating that the expected gain from harvesting Q_t exceeds the expected gain derived from producing, Q_s, thereby no household will make animal farming under modern farming technology, q_b.

Following Huffman (1991), we can mathematically derive the demand side and supply side equations separately. Depending on the first-order conditions, demand equations for the extra input (Q_f^*), straw fodder input (Q_t^*), modern feeding(Q_s^*), farming (q_b^*) and output supply such as milk yield and revenue (q_a^*) are a functions of all prices, the wage rate, fixed private and grazing land, PP and other exogenous household and village characteristics as

$$Q^* = Q\big(P_a, P_f, P_Q, W, E, \Gamma, \Lambda, \Psi\big); Q^* = Q_f^*, Q_t^*, Q_s^*, q_b^* \tag{8a}$$

Grazing and close area were expected to compete with land for food crop and crop residue so that reducing land and cattle holding. The demand for extra feed was supposed to increase with raising the price of its substitute local straw and with the economic scarcity- measured by fodder collection time. In the case of SF and breed cow adoption, PP was hypothesized to induce their adoption. Moreover, decreasing the cost of feed expense and local feed collection time induces substitution of free grazing for stall feeding and local cows for breed cows. Breed cow adoption was supposed to decline with increasing scarcity of animal feed resources. The optimal output is derived by substituting the optimal input demand functions into the technology constraint as follows:

$$q_a^{*}=q_a\left(P_a, P_Q, W, \Gamma, \Lambda, \Psi\right) \tag{8b}$$

From this, the scarcity of animal feed measured by PP was anticipated to have a positive sign in straw production, milk yield and milk income estimations up to a certain threshold and fall thereafter. Both milk and straw supplies were expected to respond positively to their own prices.

Paper 2

The Effect of Animal Feed and Water Resources Scarcity on Farm Labor and Farm Production in Northern Ethiopia

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Abstract: *Rural households in Ethiopia spend a large share of their daily time to search for grazing feed, water and collect straw. This paper examines the economic impact of time spent looking for water and grazing lands for livestock on labor to farming and on crop output based on a non-separable farm household model. To address our objectives, we estimated a general Cobb-Douglas production function using a unique dataset of 518 farmers in Tigrai, Ethiopia.*
Our results confirm a negative relationship between labor input to crop farming and resource scarcity. On average, we find that a 1 % reduction in the time spent looking for water, grazing and straw leads to an increase in food production by 0.16%, 0.28% and 0.33 % respectively.

Using level values, increasing the traveling time to water, grazing and straw sites for an animal by a 1 hour, leads to a decrease in a crop output value of 171 ETB, 189 ETB and 24 ETB respectively. When we disaggregate the data by gender, we find out that an hour reduction in searching time of scarce resource increases crop output value by about 180 ETB for male and 157 ETB for a female in the case of water and about 207 ETB for male and 141 ETB for a female in the case of grazing. An increase of crop output value of 25 ETB for male and 22 ETB for a female is also associated with an hour decrease in the straw collecting time. Depending on results from the quantile regression, the effect of these scarce resources is not uniform across the food income group, imposing a high impact on the highest quantiles and a low impact for the lowest quantiles of food production. The sign and effect of other factors are consistent with the prediction of the economic theory.

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Keywords: Resource Scarcity *Food Production; General Cobb-Douglas production: Ethiopia.*

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1. Introduction

Land degradation in Sub-Saharan Africa remains a substantial problem in aggravating poverty due to reduced availability of environmental goods and services to poor rural households, thereby increasing the labor time needed to seek for such goods (Lal & Stewart, 2010; Tesfa & Mekuriaw, 2014). Bhattacharya and Innes (2006) highlighted that forest degradation spurs rural poverty in Sub-Saharan Africa. Rural households in developing countries rely heavily on natural resource products such as fuelwood, fodder, and water to meet their daily water and feed requirements for animals. Increasing the scarcity of grazing land and water for animals can be a significant burden to poor households, as grazing land and water are key factors in livestock production (Mekonnen et al., 2015). One possible consequence is that the reallocation of labor time from crop farm activities to searching and collecting these scarce resources. Thus, reductions in agricultural output stemming from less labor input are very likely to have a detrimental welfare effect (Cooke, 1998a; Mekonnen et al., 2015).

Rural households face tradeoffs in the allocation of labor time between crop production and searching or collecting resources for energy use and feeding the animal (Mekonnen et al., 2017). The critical shortage of water and animal feed has negative implications for agricultural production because those who spend considerable time searching or collecting scarce resources may have less time left to devote for food production (Yilma et al., 2011; Mekonnen et al., 2015). In many studies of Africa, most farmers ranked fodder shortage and water scarcity as the leading constraints for animal rearing (Bishu, 2014). A recent survey in rural Ethiopia and South Africa found that fodder and water shortage combined with labor scarcity and lack of capital were major constraints limiting livestock production (Tegegne, 2012).

Increasing resource scarcity has economic implications for poor rural households. The idea that the potential effect of scarce resources is declining agricultural output as a result of reallocating inputs away from agriculture has been initially pioneered by Cooke (1998a). The literature suggests that as a result of increasing resource scarcity such as water, grazing land and animal feed, many households increase the time they spend on collecting these resources (Damte et al., 2012). It is further noted that the scarcity of animal feed and water result in lower crop productivity, which further diminishes households' food supply and incomes by increasing the work burden of all household members (Tangka and Jabbar, 2005; Mekonnen et al., 2015).

In his study in Nepal, Cooke (1998a) found that households that have higher costs of collecting environmental goods devote less time to farm activities and thus experience reductions in agricultural output. Likewise, Cooke et al. (2008) found that the scarcity of forest resource had a negative effect on agriculture in Nepal. The degree to which the amount of labor spent to collecting scarce resources takes the labor away from agricultural crop production was also examined by Mekonnen et al. (2015) in Ethiopia and show that the shadow price[6] of fuelwood has a negative

[6]Shadow prices interchangeably known as shadow cost or opportunity costs are used as a proxy for a resources scarcity. Following Cooke's (1998a, 1998b), Murphy et al. (2015) and Mekonnen et al. (2015) approach, the shadow price/shadow cost of a resource is calculated by multiplying the time spent for collection of a unit of a

and significant impact on time spent on agriculture; however, the scarcity of water for humans has no effect on time spent on agriculture. The only directly slightly related to our study is of Mekonnen et al. (2017), whose result indicated that crop farm production decreases as time spent collecting dung increases in rural Ethiopia.

The existing literature has argued that increasing scarcity of these natural resources implies increasing times for searching and collection of such resources. However, the degree to which the amount of labor devoted to these resources takes the labor away from crop production likely depends on who in the household is engaged in farming (Arnold et al., 2003). It has been commonly understood that children and women are mostly responsible for feeding and drinking animals and the scarcity of animal feed and water increases the burden on these household members. Increased load on household members' time between herding and cropping may result in lower livestock productivity and crop productivity (Mekonnen et al., 2015; Tangka and Jabbar, 2005; Wan et al., 2011). When the distances become too long for such resource collection on foot, the men tend to assume the role of resource collection and transportation using donkey carts and small trucks (Sunderland et al., 2012). Gbetnkom (2007) revealed that fuelwood scarcity had a negative significant impact on women's income-earning potential and household food security. So far the empirical evidence has been missing in support of who spends more time looking for a scarce resource and have less time for crop farming.

Thus, we noted that the evidence on the effect of natural resource scarcity (e.g., grazing land, water and straw) on agricultural output is, unfortunately, sparse. The existing studies focus mainly on the effect of these resource on labor allocation for agriculture. Rather than analyzing indicators of natural resources scarcity, an analysis of the economic impact of these scarce resources on household farm labor and crop output is required (Cooke et al., 2008; Khan, 2008). Therefore, the research questions that we want to answer are organized around four questions. First, what is the effect of these natural resource scarcity on crop farm labor input? Second, how does this resource scarcity affect household crop output? Third, is this effect uniform across food income groups? Fourth, is there a gender differential effect on crop farm labor input and crop output? We expected that the time allocation to these scarce resources reduces crop production by decreasing labor time and the effect of these scarce resources is not uniform across the food income group. We also hypothesized that the negative effect is high on male farmers as compared female farmers. To the best of our knowledge, there have been no such empirical studies dealing with this topic using rural farm dataset (Tangka and Jabbar, 2005; Cooke et al., 2008).

For this purpose, a non-separable agricultural household model was developed to be used as a framework for the analysis of farm household economics by integrating the time allocated to searching for grazing, watering and collecting straw into the model using distance level and shadow values of these resources as an indicator of scarcity[7]. Based on this analytical framework,

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resource by the imputed off-farm wage of that village where collection or searching time is simply the inverse of the constant marginal product of collection or searching time.

[7] See for a similar approach in the work of (Cooke, 1998a; Cooke et al,. 2008 and Baland et al., 2010)

an econometric estimate was presented using the NMBU-MU[8] Tigrai Rural Household Surveys (2015) dataset collected under the sponsorship of NORHED project. This analysis was conducted in order to test the hypothesis that increasing time spent on searching for grazing land and water for animals and collecting straw has a negative effect on farm labor time and crop farm production. At the same time, we also hypothesize the effect of these scarce resources is not uniform across the different food income groups.

Our findings support the hypothesis of a negative relationship between total labor input to crop farming and resource scarcity. Likewise, in aggregate the findings confirm that reducing time spent looking for water by 1% leads to an increase in food production by 0.16% while a 1% decrease in time wastage for searching grazing land increases food production by 0.28%. Besides, an increment of 0.33% in food production is achieved by a 1% reduction in straw collecting time. Using level values, increasing the traveling time to reach water, grazing and straw sites for an animal by a 1 hour, leads to a decrease in a crop output value of 171 ETB, 189 ETB and 24 ETB respectively. Likewise, our results show that a moderate significant difference of crop output value between male and female resulting from a resource scarcity. The quantile regression also proved that the effects of these scarce resources are heterogeneous.

The significant contribution of this paper is, unlike previous studies, we collected information on the entire set of crop production, along with the distance to grazing, water and crop residue of each household. The only studies that consider the effects of scarce environmental goods on agricultural labor input are of Cooke (1998a), Kumar and Hotchkiss (1988) in Nepal and Mekonnen et al. (2015) in Ethiopia. However, these studies considered the effect of time spent on the collection of fuelwood, leaf fodder, dung and grass on labor time but not directly on crop production. This paper firstly tries to examine the effect of these scarce resources on labor to crop farming and crop output, which is ultimately what policy-makers seek to know (Khan, 2008). Second, this paper considers three important resources for an animal such as grazing, water and crop residue, of which the first two have not been explored well. The use of distance level and shadow price of these resources as resource scarcity indicators is an extra contribution to the literature. Ethiopia is an important case for the purpose of this study. From a practical and policy perspective, it is relevant to understand how farmers respond to these scarce resources.

2. Literature Review

In Ethiopia, livestock contribution accounts for 40%, excluding the values of draft power, manure, and transport service (Asresie and Zemedu, 2015). Ethiopia is a home of 35 million Tropical Livestock Unit (TLU)[9], and on average, one TLU requires about 25 liters of water per day. Despite its large population size, the contribution is said to be deteriorating (Ilyin, 2011). Livestock production in the country depends on the quantity of grazing land and water (Bezabih & Berhane, 2014). The livestock sector is a key player in increasing water use and water depletion (Steinfeld et al., 2006). Both human and livestock suffer from water shortage. In many parts of the

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[9] The tropical livestock unit is commonly taken to be an animal of 250 kg live weight (FAO 1987)

country, most of the year, animals have to walk long distances in search of water. Belay et al., (2013) in their study concluded that (100%) and (27%) of survey farmers respectively perceived that feed and water shortage are the most important problems of livestock production in Ethiopia so that livestock suffers from a seasonal shortage of grazing land and water.

The availability of crop residues and natural pasture are gradually declining as a result of crop expansion, settlement and land degradation (Gebremedhin, 2009). In many parts of the highlands, animal feed and water deficits start in December–January, when the natural pastures are at their lowest quantity and the supply of stored crop residues is beginning to diminish (Sileshi et al., 2003). The report for CSA (2010c) reported that out of the 16 million ha agricultural land, 75 % is used for crops while grazing land accounts for 9%. In line to this, Tesfay (2010) revealed that the natural grazing in Tigrai is diminishing over time due to chronic degradation and shrinking the grazing land sizes. Based on Tesfaye (2010), the estimated crop residues from cultivated land contributes only about 45% of the animal feed demand in the region. It is stated that 73% of the animal feed is provided from natural grazing, 14% from crop residues, and the remaining 13% from other feed sources. Likewise, Hassen et al. (2010) revealed that the shortage of water and feed are common in the dry season as compared to the wet season.

The well-being of Ethiopians heavy depends on farm and range land, water and climatic resources due to the dependence of the majority of the Ethiopian people on subsistence agriculture. The increasing scarcity of these resources means increasing collection times (Guarascio et al., 2013). Shrinking access to the scarce resources near the home, which is becoming a pressing reality in many developing countries and the time taken to search and collect them often imply that farmers have left less time for other activities. This adds to the labor burden of women, as traditional roles such as raising children and cooking make women often work much longer hours than their male spouses (Kes and Swaminathan, 2006; Wan et al., 2011). It has been commonly understood that children and women are mostly responsible for feeding and drinking animals and that their scarcity increases the burden on these household members.

Herders mostly boys frequently travel long distances, with animals in search of feed and water when feed scarcity increases household members and livestock mobility (Tangka and Jabbar, 2005). Likewise, when the distances become too great for resource collection on foot, men tend to assume the role of resource collection and transportation using donkey carts and small truck (Sunderland et al., 2012). Thus, increased competition on household members' time between herding and cropping, may result in lower livestock productivity and crop productivity as well (Mekonnen et al., 2015; Tangka and Jabbar, 2005; Wan et al., 2011). Lower livestock productivity and crop productivity under crop-livestock mixed system, the overall effect of feed scarcity is lower livestock income from sale of livestock and livestock products, reduced access to food, increase labor burden of all household members, and reduced food and nutrition security for human welfare (Tangka and Jabbar, 2005).

One potential effect for concern is declining agricultural output as a result of reallocating inputs away from agriculture. The pioneer study by Cooke (1998a) revealed that a reallocation of time away from farm work occurs as environmental goods become scarcer in Nepal. The work of

Kumar and Hotchkiss (1988) also found that time spent in crop farming declines with a higher degree of fuelwood scarcity. The findings of Tangka and Jabbar (2005) in Kenya show that feed scarcity increases livestock traveling distances in search of feed and water, resulting in lower livestock and crop output by increasing household' time for collection. Likewise, Cooke et al. (2008) explained the effect of forest scarcity on the livelihood of rural people in Nepal and found negative effects on agriculture.

Bandyopadhyay et al. (2011) found that more time spent on scarce fuelwood was associated with negative welfare in Malawi. Another related study by Damte et al. (2012) in Ethiopia indicated that rural households respond positively to fuelwood shortages by increasing their labor input. Mekonnen et al. (2015) show that fuelwood scarcity has a negative and significant impact on time spent on agriculture. Similarly, Mekonnen et al. (2017) concluded that agricultural productivity decreases with increasing time spent on collecting animal dung but increases with time spent on collecting crop residue. From the above brief review of related works, we noted that the evidence on the effect of natural resource scarcity on agricultural output is, unfortunately, sparse. Evidence from Africa is even scarcer in the existing studies. Hence, this paper will contribute to the sparse empirical evidence from sub-Saharan Africa (Cooke et al., 2008; Khan 2008) by exclusively analyzing the economic effect of these scarce resources on household labor input and crop production.

3. Theoretical Model

In rural farm households, total time endowment is normally divided into three main activities: farm activities, off-farm activities and leisure. The scarcity of grazing and water resources also takes the largest proportion of family labor time in countries like Ethiopia, characterized by a critical shortage of animal feed and water, having negative implications for agricultural output (Tangka and Jabbar, 2005). Hence, considering this labor time, the total time endowment is further divided into four main activities: farm activities, off-farm activities, leisure and searching or collecting scarce resources activities.

The collection of scarce resource displaces labor from productive activities such as agricultural production and off-farm employment (Damte et al., 2012; Mekonnen et al., 2015). A tradeoff between labor used for searching grazing, water and collecting straw and that used as an input to crop production has remained unexplored in the literature (Bandyopadhyay et al., 2011). This scarcity adversely affects rural household's welfare in five paths by taking labor away from crop farming, meal cooking and leisure; by weakening the energy of cattle used as power track and meat/milk production, and by depleting crop residue used as soil fertilizer.

In this paper, we try to examine the link between animal resource (grazing land, water and straw) scarcity approximated by walking distance and shadow price and the monetary value of agricultural food production using a theoretical framework which fits into a larger family of agricultural household model (AHM) developed by Strauss (1986a) and later modified by Palmer and MacGregor (2009). We applied a non-separable AHM to consider imperfections, or absence of, markets for grazing, water, straw and labor used in searching or collection.

For simplicity, we assume that household derives utility from the consumption of own produced goods X_o (meals prepared from own crop grain such as wheat and animal good such as milk and meat etc.); other purchased goods (X_m), and leisure (L_l). The household utility is affected by a vector of exogenous household characteristics (Ψ), such as human capital, age, and household size and that condition household consumption decisions. Households maximize their utility function subject to a set of production, budget, and time constraints:

$$U= U(X_o, X_m, L_l; \Psi) \quad (1)$$

Household goods X_o are produced with inputs i.e. fuel straw or dung E_f, mostly collected from communal land. This meal is assumed to be a function of agricultural products coming from crop grain and animal goods (Q_a), off-farm income (W_o) as well labor days the household spends on searching grazing land (L_g), water (L_w) and collecting crop residue (L_r). The production of household goods is also influenced by the vector of household characteristics ϕ pertaining to consumption such as the type of house, stove technology etc. The production constraints for the meal production can be described as

$$X_o = f_{X_o}\left(E_f, Q_a, W_o, L_g, L_w, L_r; \phi\right) \quad (2)$$

The agricultural production Q_a, is produced using household labor, L_a, a vector of other agricultural inputs (X) and household characteristics (H). Production also depends on the amount of labor spent on searching for grazing and water as well as collecting crop residues $\left(L_g, L_w, L_r\right)$ as a proxy measure for scarcity of these resources that withdraw labor from crop farming activity.

$$Q_a = f_{Q_a}\left(L_a, X, H, L_g, L_w, L_r\right) \quad (3)$$

Denoting the total family labor endowment of the household by L_T, farmers time constraints can be given by

$$L_T - L_a - L_g - L_w - L_r - L_o - L_l \geq 0 \quad (4)$$

If we define that (E) is farmers' exogenous income obtained from network relatives or safety net activities, and median village price for agricultural outputs, inputs and other purchased goods as P_a, P_x, and P_m, then the household's budget constraint is

$$P_a Q_a + W_o L_o + E \geq P_x X + P_o X_m \quad (5)$$

Thus, the objective of the farm household is to maximize the utility function(1) subject to (a) time constraints 4 (b) budget constraints 5 by substituting the production function 3 into the budget constraint and (c) the non-negativity on the choice variables.

$$\underset{L_a, L_g, L_w, L_r, L_o, L_l, X_m, X}{\text{argMax}} \; U\left(X_o\left(E_f, Q_a, W_o, L_g, L_w, L_r; \phi\right), X_m, L_l; \Psi\right)$$

$$\text{s.t.}$$

$$L_T - L_a - L_g - L_w - L_r - L_o - L_l \geq 0$$

$$P_a Q_a\left(L_a, X, H, L_g, L_w, L_r\right) + W_o L_o + E \geq P_x X + P_o X_m$$

$$L_a, L_g, L_w, L_r, L_o, X \geq 0$$

$$L_l, X_m > 0 \quad (6)$$

The fact that some leisure is always reserved and a positive amount of other goods are consumed indicated that L_l *and* X_m are assumed to be strictly positive. Assuming an internal solution, the Lagrangian for this optimization problem becomes:

$$Ł= U\big(X_o\big(Q_a\big(L_a, X, H, L_g, L_w, L_r\big), E_f, W_o, L_g, L_w, L_r; \phi\big), X_m, L_l; \Psi\big) + \gamma\big[L_T - L_a - L_g - L_w - L_r - L_o - L_l\big] + \eta\big[P_a Q_a\big(L_a, X, H, L_g, L_w, L_r\big) + W_o L_o + E - P_x X - P_o X_m\big] \quad (7)$$

The Khun-Tucker first-order conditions are derived as follows:

$$\frac{\partial Ł}{\partial L_a} = \frac{\partial U}{\partial X_o}\frac{\partial X_o}{\partial Q_a}\frac{\partial Q_a}{\partial L_a} - \gamma + \eta P_a \frac{\partial Q_a}{\partial L_a} = 0, \quad L_a \geq 0 \quad (8)$$

$$\frac{\partial Ł}{\partial L_g} = \frac{\partial U}{\partial X_o}\frac{\partial X_o}{\partial Q_a}\frac{\partial Q_a}{\partial L_g} + \frac{\partial X_o}{\partial L_g} - \gamma + \eta P_a \frac{\partial Q_a}{\partial L_g} = 0, L_g \geq 0 \quad (9)$$

$$\frac{\partial Ł}{\partial L_w} = \frac{\partial U}{\partial X_o}\frac{\partial X_o}{\partial Q_a}\frac{\partial Q_a}{\partial L_w} + \frac{\partial X_o}{\partial L_w} - \gamma + \eta P_a \frac{\partial Q_a}{\partial L_w} = 0, L_w \geq 0 \quad (10)$$

$$\frac{\partial Ł}{\partial L_r} = \frac{\partial U}{\partial X_o}\frac{\partial X_o}{\partial Q_a}\frac{\partial Q_a}{\partial L_r} + \frac{\partial X_o}{\partial L_r} - \gamma + \eta P_a \frac{\partial Q_a}{\partial L_r} = 0, L_r \geq 0 \quad (11)$$

$$\frac{\partial Ł}{\partial L_o} = \eta W_o - \gamma = 0, L_o \geq 0 \quad (12)$$

$$\frac{\partial Ł}{\partial L_l} = \frac{\partial U}{\partial X_o}\frac{\partial X_o}{\partial L_l} - \gamma = 0, L_l > 0 \quad (13)$$

$$\frac{\partial Ł}{\partial X} = \frac{\partial U}{\partial X_o}\frac{\partial X_o}{\partial Q_a}\frac{\partial Q_a}{\partial X} + \eta P_a \frac{\partial Q_a}{\partial X} - \eta P_x = 0, X \geq 0 \quad (14)$$

$$\frac{\partial Ł}{\partial X_m} = \frac{\partial U}{\partial X_m} - \eta P_m = 0, X_m > 0 \quad (15)$$

Equations (8-13) show how the household allocates it's time for crop farming, searching for grazing land and water, collecting crop residue, off-farm and leisure activity. For instance, if the household spends time searching for grazing land[10], $L_g > 0$, the Khun-Tucker first-order condition indicated that $\frac{\partial Ł}{\partial L_g} = 0$. Thus equation (7b) becomes

$$\frac{\partial X_o}{\partial L_g} = \gamma - \frac{\partial Q_a}{\partial L_g}\left(\frac{\partial X_o}{\partial Q_a} + \eta P_a\right) \quad (16)$$

In this equation, the left part shows the value of marginal utility of the household from consumption of own goods -meals prepared from own crop grain and animal goods such as milk and meat coming from animals whose source of feed is the scarce grazing land. For an inequality constraint, γ and η represent non-negative Lagrangian multipliers for the time constraint and full income constraints. The local agricultural output market price, P_a, is positive. The marginal utility derived from the consumption of own goods which comes from the increased agricultural output $\left(\frac{\partial X_o}{\partial Q_a}\right)$ is also assumed to be non-negative. The right-hand side of equation (16) becomes positive

[10] Similarly, if the household spends time in searching water for animal ($L_w > 0$) or in collecting crop residues ($L_r > 0$), the first order conditions with respect to L_w and L_r (10 and 11) provide similar to the equation displayed in (16) above with the only exception that the term L_g is respectively replaced by L_w and L_r

if the marginal effect of using labor searching for grazing land on the agricultural output $\left(\frac{\partial Q_a}{\partial L_g}\right)$ is negative. This implies that the right-hand side of equation (16) represents the marginal effect of spending labor searching for grazing land in terms of lower agricultural product and the extra negative burden it imposed on households' time and budget constraints(γ and η).

Equations (16) stated that household allocates labor for searching grazing land until the marginal utility of labor used for grazing equals the marginal cost of household labor. If we use the first-order conditions for searching water or collecting crop residues, instead of grazing land, a similar result to that of Equations (16) will follow. The main question that interests us is whether the scarcity of these resources adversely affects crop production. The hypothesis to be tested is that farmers that spend more time on searching these scarce resources are likely to be less productive in crop production that is we test weather $\frac{\partial Q_a}{\partial L_g}$<0, or $\frac{\partial Q_a}{\partial L_w}$<0, or $\frac{\partial Q_a}{\partial L_r} < 0$ using a level and shadow values[11] of these resources as an indicator of scarcity in the study area.

4. Study Area and Dataset

The study is conducted in the Tigrai region, the northern part of Ethiopia on cross-sectional survey data from NMBU-MU[12] Tigrai Rural Household Survey (NM-TRHS) collected in the year 2015 from 632 sample households. The data[13] includes a panel of five rounds conducted in 1997/98, 2000/01, 2002/03, 2005/06 and 2014/2015 where the author is involved only in collecting the data for the last round. Initially, to reflect systematic variation in agro-climatic conditions, agricultural potential, population density and market access conditions, four communities were selected from each of the four zones and three communities that represent irrigation projects. Likewise, one with low population density and one with high population density were strategically selected from each zone among these communities to reflect far distance from the market (Hagos, 2003).

This paper uses only cross-sectional data for the year 2014/2015 extracted from the survey for the simple reason that some outcome and explanatory variables were only added in the last round. For this study, the need for information regarding livestock activity restricted us to use only 518 livestock owner-farmers. Table 1 presents the basic socio-economic characteristics for the 518 farm households. The dependent variables in this paper are labor time for crop farming and aggregate household agricultural crop production or monetary value of all crops produced during the survey production season. Multiple crop outputs are aggregated into a single output measure using the medians of their reported village's prices within each village following Jacoby (1993), Klemick (2011) and Gutu (2016). An average household owns a production farm capital tools worth about 639 ETB[14] and has produced an average agricultural output of worth 41,645 ETB in the year, with an average total income including livestock, off-farm, transfer and business to be

[11] See for a similar approach in the work of (Cooke, 1998a; Cooke et al., 2008 and Baland et al., 2010)
[12] Norwegian University of Life science -Mekelle University
[13] This dataset has been used by Holden et al. (2009, 2011).
[14] ETB refers to Ethiopian currency where 1USD≈24 ETB during the study year,2015

49,426 ETB. In addition, on average each household spent 683.6 labor hour for crop production per cultivating and harvesting season and around 274 labor hour is allocated to livestock rearing excluding child labor time for the same season.

There are two methods of scarcity measures: physical measures and economic measures in the literature on resource scarcity. Physical measures, such as the distance from the resource (fuelwood, water, grazing, fodder) or village-level availability of these resources (as applied by Cooke, 1998a, 1998b; Kumar and Hotchkiss, 1988; Cooke et al., 2008; Veld et al., 2006; Damte et al., 2012; Mekonnen et al., 2015; Mekonnen et al., 2017 and Hadush, 2018). However, labor shortages in rural areas are often more important for household fuelwood-use decisions than physical scarcity of fuelwood. This makes that physical measures are not a reliable indicator of resource scarcity. The opportunity cost of the time spent searching or collecting is, therefore, considered to be a better measure (Cooke et al., 2008; Damte et al., 2012). The name of opportunity cost is interchangeably known as shadow price or shadow cost) of resources and can, therefore be different from the market price (Strauss, 1986a).

The opportunity cost is commonly approximated using two ways as demonstrated by (Cooke, 1998a, 1998b; Baland et al., 2010; Murphy et al., 2015; Mekonnen et al., 2015; Hadush, 2018), who used the wage rate multiplied by the time spent per unit of environmental good collection, as a measure of scarcity, and as the marginal product of labor in resource collection multiplied by the shadow wage (Mekonnen, 1999). Besides, shadow wage or shadow price are calculated by the ratio of predicted outputs to labor time multiplied by the coefficient of labor derived from the Cobb-Douglas production function following Jacoby (1993) and Le (2010). Due to missing data for the estimation of the economic scarcity, which requires an exclusion restriction, we use only physical indicators of scarcity.

Despite straw has a local market price and is therefore relatively easy to value, grazing land and water, however, are challenging to value because they are not traded and have no market price; thus, their prices are shadow prices (Magnan et al., 2012). Shadow prices/shadow costs are assumed to reflect better the economic scarcity of environmental goods to a household (Cooke 1998a). For this reason, first, we use walking time to measure grazing, water and crop residue using the similar method used by Palmer and MacGregor (2009) and Amacher et al. (1993) as a proxy indicator of the scarcity of these resources. On average, the households spend 1.25 hours to reach a water source for animal and 1.31 hours to search for communal grazing land daily per a single trip, with a maximum time reaching up to 6 hours for water site and 8 hours for grazing land in the data. Besides, the average time spent on collecting straw by the households is 9 hours, ranging from a minimum value of 0.3 to a maximum value of 100 hours per collecting season.

Second, following to Cooke (1998a, 1998b), Damte et al. (2012), Baland et al. (2010), Mekonnen et al. (2015) and Hadush (2018), we measure the shadow costs of natural resources (grazing and water) as well as collecting crop residue as the time taken to reach grazing land and water sites or to collect crop residue per its amount collected multiplied by the village adjusted[15]

[15] In order to adjust for big variation in the wage rate among villages of the region, the wage rate is adjusted using a

off-farm wage. In this paper, we take the wage rate for those who report working for an off-farm wage in the local labor market and the wages from those who did not report working were missing but imputed following Heckman (1979) two-stage approach as is applied by Cooke (1998a, 1998b). It has been popular to impute wages of non-employed persons from the wage equation, which describes the functional relationship between the wage and personal characteristics such as age, marital status, and place of living, work experience and occupation.

The wage equation is typically modeled within the linear regression model and estimated using the sample of employed persons. However, such an approach, which uses only data on employed persons is criticized by Heckman (1979) and suggested the two-stage model, consisting of a wage equation and a participation equation, in which the latter estimates the probability of a person to be employed vs. non-employed. This has been popular among researchers and widely applied for prediction of wages of non-employed persons for labor supply and estimation of the gender wage gap (see for detail; Labeaga et al., 2008; Breunig and Mercante, 2010).

In this way, we produce a household specific shadow price/shadow cost of searching for grazing land or water and collecting straw. Using this data in Table1, the average shadow price/shadow cost for animal watering is about 147 ETB per day which is equivalent to the average daily rural wage rate in the region. On average, the shadow price of searching grazing is 205 ETB per day, which is greater than the shadow price of water and straw. This is not surprising, as rural farmers usually spend a huge amount of time in searching grazing than watering. As expected, the shadow price of collecting a straw is 12 ETB per trip.

5. Empirical Model Specification

This paper draws on the Agricultural Household Model (AHM) which provides a holistic framework to analyze the economic effect of resource scarcity on labor to crop farming and the monetary value of crop production in the farm household. Based on the reduced form equations derived from AHM, we first model labor allocation to crop farming as a function of resource scarcity and household characteristics following Cooke (1998a) and Mekonnen et al. (2015). The choice of functional form for the estimation of the monetary value of crop production function with respect to different inputs has gained substantial attention in the economic literature. With regard to estimation, the production function is mostly estimated using the Cobb-Douglas production function since the output is a simple function of labor and capital. However, this does not allow other variables than just the two which can significantly affect production such as fertilizer and land. For this reason, the General Cobb-Douglas (GCD) production function developed by Diewert (1973) was adopted in order to incorporate these variables into the production function.

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general informal rural labor conversion factor, 0.98. During the survey, we have asked wages from three types of markets: the village market, *tabia* market and district market. In this paper, we used the village wage reported by those households who participated in the village labor market.

The GCD production function that satisfies the non-negative, non-decreasing, continuous and quasi-concave properties of standard production function is denoted by

$$Q = \quad m\prod_{i=1}^{n}\prod_{n=j}^{n}\left(\frac{1}{2}x_i + \frac{1}{2}x_j\right)^{\alpha_{ij}} \qquad (11)$$

Where $-Q$ is output in the aggregate monetary value of crop production, $x_1,\ldots, x_n$ are quantities of the n inputs of production and not the negative inputs of production, m> 0, $\alpha_{ij} = \alpha_{ji}$ and $\sum_{i=1}^{n}\sum_{j=1}^{n}\alpha_{ij} = 1$(This is the assumption of a constant return to scale).Assuming that α_{ij}=0 for all $i\neq j$, and taking the natural log of equation (11) produces a standard Cobb-Douglas equation with many inputs, which is to be estimated in its natural log form:

$$\ln Q = \alpha_0 + \sum_{i=1}^{n}\alpha_i \ln x_i + e \qquad (12)$$

Where $\alpha_0 = \ln m$ (m is the constant term in equation (11), and e is the error term. The GCD production function is often criticized for being restrictive due to its assumptions of constant returns to scale (CRTS) and perfect competition in both input market and output market even if it can handle a large number of inputs. Its assumptions make it difficult to measure technical efficiency levels and growth effectively. But the assumption about market does not significantly affect the estimation power of Cobb-Douglas production function as long as factors are paid according to their relative shares (Murthy, 2004). In addition, Miller (2008) argued that GCD can be estimated by relaxing the CRTS assumption and then test whether the summation of the coefficients is significantly different from one using the standard econometric procedure.

6. Empirical Results and Discussions

6.1. Resource Scarcity on Allocation of labor for Crop Farming

What are the consequences of increasing grazing, water and straw scarcity for crop labor input? We answer this question by examining the link between resource scarcity and labor input to crop farming in rural areas of Ethiopia using similar estimation methods as Cooke (1998). In this paper, the main variables of greatest interest are animal water and feed scarcity measured by the time taken to reach them. A priori*,* animal water and feed scarcity should reduce labor time on the crop farm because they take away time from crop farms and leisure as people search for these resources. Using ordinary least square (OLS) on log-log function, the estimate of the effect of resource scarcity on time spent in crop farming is presented in Table 2. For the sake of reliable estimation, 16 distorting observations or outlier were dropped from the dataset in this estimation.

Our results do support the hypothesis of a negative relationship between total household labor allocation to crop farming and resource scarcity at the household level. With respect to the variables of interest, higher searching times of water, grazing and collecting straw were shown to significantly reduce labor time to crop farming. We found that a 1% increase in searching times of water, grazing and collecting straw results in a 0.06%, 0.09% and 0.10% respectively decrease in time spent on a crop farm. Using level values in linear regression, we also found that increasing time spent to reach water, grazing and straw sites by an hour lead to a decrease in a crop farm labor of 10.8 hours, 9.7 hours and 2 hours respectively. This result finds favor among a number of researchers (Cooke, 1998a; Cooke et al., 2008; Bandyopadhyay et al., 2011; Mekonnen et al., 2015). We found significant effects of other covariates as well. Land area in crops has a significant positive correlation with total household labor input to farming. Real off-farm wage has a significant positive effect on household farm labor input.

As expected, we also found that large family households spend more time per person on crop farming. The households living in lowland areas spend more farm labor input to farming than their counterpart. Wealthier households who have more livestock spend more time for farming. Higher on-farm income is associated with household's more time input to crop farming. Hiring labor from the local market decrease labor family input to farming and farmers living a high altitude tend to allocate more labor input to crop farming. These findings correspond to the results of previous studies by Cooke (1998), Okwi & Muhumuza (2010), Bandyopadhyay et al. (2011) and Mekonnen et al. (2015).

6.2 Resource Scarcity on Monetary Value of Aggregate Crop Production

For the sake of reliable estimation, outliers are removed from the dataset. Thus, 9 distorting observations were dropped from the dataset in crop output value estimation. In order to estimate the production sector of the farm households, we used ordinary least square (OLS) on the log-transformed form of the GCD production function specified in section 5. The dependent variable is the monetary sum of all crops produced during the survey harvesting season. The estimates of the crop output value using walking distance and shadow values of water, grazing land and straw are presented in Tables 3 and 4. In general, the estimation shows that all explanatory variables exhibit significant and theoretically expected signs.

Variables of interest in this paper are time spent on looking at water and feed resources included so as to capture the effect of resource scarcity on agricultural output value. The first column of Table 3 presents the estimation of log output with water scarcity taken into account as do the second and the third columns, putting grazing land and straw collection into consideration. The result is in favor of our hypothesis. As expected, Column (1) of Table 3 indicated that time spent on animal water source is found to be negative and significant, suggesting that a 1% increase in time spent looking for water decreases crop output value by 0.16%, and time spent on searching grazing have a stronger effect than this variable as shown in Column (2) i.e., a 1% increase in time spent searching for grazing decreases agricultural output by 0.28%. Another scarcity related variable is time spent for collecting straw which significantly resulted in a negative sign, implying that farmers that spend 1% more minute for collecting straw produce about 0.33% less output value (Column 3).

Using level values, Table 5 reports a linear-linear estimation of output between the crop output value and resource scarcity. For the sake of simplicity, only coefficients of variables of interests are interpreted here. The results across the three columns (Pool. Male and Female) and different estimators are quite similar (Table 5). An increase of one hour in the traveling time to water and grazing sites for the animal, leads to a decrease in the crop output value of 171 ETB and 189 ETB respectively. Likewise, an increase of 24 ETB in the crop output value is associated with an hour reduction in the straw collecting time in favor of the findings of (Cooke et al., 2008; Mekonnen et al., 2015; Mekonnen et al., 2017).

The output effect obtained here support the claim that time spent for searching scarce resources displace labor time from production activity and hence reduce crop output (Mekonnen et al., 2015; Damte et al., 2012; Tangka & Jabbar, 2005; Cooke et al., 2008). For comparison purpose, the estimates of the effect of these resource scarcity on crop output value are also presented in Table 4 using their shadow prices. In line with our expectation, we found that water scarcity reduces crop output value. The results suggest that a 1% increase in the shadow price of water for animal results in a 0.07% decrease in agricultural output value. The effect is lower as compared to the effect of distance value in Table 3. Agricultural crop value also decreases as the shadow price for grazing land increases; on average, a rise in 1% in the shadow price of reaching grazing land implies a fall of 0.09% in crop output produced. The significant and large effect of grazing scarcity on the crop output is because farmers with larger large cattle require more labor time for searching better grazing.

The strongest negative significant result on any of the shadow prices is for the straw shadow price. The coefficient on the shadow price of collecting straw indicates that a 1% increase in shadow price reduces crop output by 0.15%. This is consistent to the idea that the potential effect scarce resources is declining agricultural output as a result of reallocating inputs away from agriculture (Cooke et al., 2008; Mekonnen et al., 2015; Mekonnen et al., 2017), which further support the downward spiral hypothesis that resource degradation lead to poverty (Aggrey et al., 2010; Yang et al., 2015).

The estimated coefficient for land (0.278, 0.304 and 0.201) shows that when landholding increase by 1% agricultural production increases, on average, by almost 0.3%, implying that land is a vital input of agriculture. The result is similar to what it was found by Sarris *et al*. (2006) in Tanzania. As expected, fertilizer and manure use are found to be significant and positive variables indicating that a 1% increase in fertilizer and manure use leads to a 0.15% and 0.09% increase in agricultural outputs incongruent to the studies conducted by (Demeke et al., 2011; Di Falco et al., 2011), whose result revealed that fertilizer and manure use positively and significantly affected food production in Ethiopia. In Ethiopia, the ox is the main capital input and can be considered as an equivalent substitute for the uses of the tractor. In this paper, the number of oxen is found to be significant, leading to a 0.23% increase in the agricultural output. A similar result is found in the study of Mekonnen et al. (2015) who found a positive effect of ox input on food crop productivity in Ethiopia.

In line with the predictions of economic theory, a 1% increase in man-day labor causes to increase farm output by about 0.35%, a finding that is consistent with the notion that labor has a positive effect on production (Di Falco et al., 2011; Abdulai and Huffman, 2014) but the coefficient on seed input contrasts with the findings by Di Falco et al. (2011) in Ethiopia and Bulte et al. (2014) in Tanzania. Farmers hiring an extra labor seems to increase their production value by 0.48%. Another capital input included in the analysis is production capital which is the monetary value of farm tools. A 1% increase in production capital has the ability to increase agricultural output by 0.06%. This finding supports the earlier study by Sarris et al. (2006).

Not surprisingly, we found that an increase in shock has a quite large detrimental effect on food production (-2.16%) which is consistent with a previous study (Abdulai and Huffman, 2014) who confirmed a negative effect of drought or illness shock on production. The variable representing education of the farmer is positive and significantly different from zero, suggesting that more educated farmers are more likely to produce more in favor of Abdulai and Hoffman's (2014) result.

Table 5 further provides a disaggregate analysis by gender. When we disaggregate the data by gender, we find out that a one hour reduction in the traveling time to water sites for animal increases crop output value by about 180 ETB for male and 157 ETB for female, while the coefficient of grazing signals a decrease of 207 ETB for male and 141 ETB for female as a result of one hour reduction in searching time for grazing. Our results also show that a decrease in the straw collecting time is associated to a significant increase in the crop output value of 25 ETB for male and 22 ETB for female. The coefficients in all cases are negative, similar to findings in other studies (Wan et al., 2011; Gbetnkom 2007; Tangka and Jabbar, 2005; Sunderland et al., 2012).

An alternative is to estimate quantile regressions on farm output in order to capture the effects of these scarce variables across the entire distribution of the dependent variable (Koenker and Basset, 1978). The elasticity values associated with a 1% change in distance to a water on crop output values range from -0.16% for the second bottom quantile to -0.13% of top quartile with a median value of -0.18% in Table 6, resulting in an overall reduction of 0.18% in food crop production value. The median distance to the grazing land elasticity of food production is -0.23%. For those in the 10th category of the food output distribution, a reduction in grazing distance could increase their output by about 0.22%, reaching a maximum effect of 0.45% for those in the last top quantile. Lastly, the time spent for straw collection elasticity of food output is -0.26% at the median value but ranges from -0.23% for the 10th to -0.48% for the 100th as shown in Table 6. Similar results are found using the shadow value in Table 6. This is evidence that treating all quantiles as one and hence estimating only one coefficient such as in OLS would be misleading both for policy and inference.

7. Tests of Separability

In order to test for separability (that is whether the labor market or straw market functions well), we examined the relationship between the estimated shadow wages /price ($shadowV$) and market wages/prices ($marketV$) reported by the household who participate in off-farm or straw market using similar method in Jacoby (1993) and Skoufias (1994). The regression

$$shadowV = \beta_0 + \beta_1 marketV + \varepsilon \qquad (13)$$

Where $shadowV = Q/D \times \delta_L$ which represent shadow wage or shadow price calculated by the ratio of predicted outputs (Q) to labor time (D) multiplied by the coefficient of labor derived from the Cobb-Douglas production function following Jacoby (1993) and Le (2010).The test for the SM is whether β_0= 0 and β_1 = 1, under the null, the market price reflects the value of the marginal product of labor or straw. We report the results in Table 7 which is obtained from the regression of the form. The results strongly rejected the existence of separability, implying that the estimated shadow wage/prices are a more accurate basis for understanding the farming decision in a rural area.

8. Conclusion and Suggestion

In rural farms, households spend a large share of their daily time on searching animal grazing and water as well as collecting crop residue. This directly impacts farm production by displacing labor from production activity. This study analyzes the economic implication of animal water and feed scarcity on labor farming and farm production in North Ethiopia using non-separable agricultural farm household model. To address our objectives, a general Cobb-Douglas production function was estimated using a unique dataset from 518 sample farmers.

The results of this paper provide an interesting picture of stallholders in Ethiopia. As expected, it appears that time spent searching for animal water and feed has a significant and negative effect on labor and crop output. Our results got the evidence of a negative relationship between labor input to crop farming and resource scarcity. We found that a 1% increase in searching times of water, grazing and collecting straw results in a 0.06%, 0.09% and 0.10% respectively decrease in time spent on a crop farm. We also found that increasing time spent to reach water, grazing and straw sites by a 1 hour leads to a decrease in a crop farm labor of 10.8 hours, 9.7 hours and 2 hours respectively using level values in linear-linear model estimation.

In aggregate, reducing time spent looking for water and grazing by 1% leads to an increase in food production by 0.16% and 0.28% respectively, and an increment of 0.33% in food production is achieved by 1% reduction in straw collecting time. Similarly, the shadow price variable are significant, have the expected negative sign and is consistent with the theoretical predictions in that reduction of 0.07%, 0.09% and 0.15% in crop output are reported by a 1% increase in the shadow price of water, grazing and straw respectively. Using level values, increasing the traveling time to water, grazing and straw sites for an animal by a 1 hour, leads to a decrease in a crop output value of 171 ETB, 189 ETB and 24 ETB respectively. When we disaggregate the data by gender, we find out that a 1 hour reduction in searching time of scarce resource increases crop output value by about 180 ETB for male and 157 ETB for female in the case of water and about 207 ETB for male and 141 ETB for female in the case of grazing. An increase of crop output value of 25 ETB for male and 22 ETB for female is also associated with a 1 hour decrease in the straw collecting time. Depending on results from the quantile regression, the effect of water and feed scarcity is not uniform across the food production distribution.

In general, this study can be helpful for policymakers working to alleviate animal water and feed problems in Ethiopia to justify their actions with an empirical result. Based on the empirical results presented, two areas of policy intervention can be emerged as relevant: the first involves policies that facilitate easier access to water tap for animal by advocating for emergency relief projects by the local government and non-government development agents. Then, this requires the substitution of possessing more quantity of cattle by a less number with more quality. The second area of policy intervention involves the introduction of more efficient animal feed management strategy with new livestock technologies such as the adoption of improved cows, bi-products, fattening and stall feeding practices that improve cattle production and reduce land degradation. Given the evidence in this paper, it appears that policies that seek to promote information via TV and radio about how to optimally allocate their daily time to livestock feeding and its negative effect on crop faming would be useful in enhancing household level food security. A further research should focus on adopting an approach using welfare indicators and longitudinal data in the same study area.

Declarations:

Availability of data and Materiel

The dataset used in this paper is available and accessible upon request from the corresponding author

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Table 1. Descriptive and Summary Statistics

		N=518	
VARIABLES	Description	Mean	SD
Dependent Variables			
Output	Monetary value of crop production in ETB[a]	41,645	87,517
Income	Monetary value of total income in ETB[b]	49521	92,642
Independent Variables			
ShadowPW	Shadow price of watering, ETB/single trip	147.6	204.9
ShadowPG	Shadow price of grazing, ETB/single trip	205.0	282.0
ShadowPF	Shadow price of straw, ETB/ donkey load/season	12.52	18.96
WaterD	Time to reach for water in minute /day/single trip	74.85	65.54
GrazingD	Time to look for grazing in minute / day/single trip	91.12	83.44
FeedD	Time to collect straw in minute /year/single trip	576.55	557.87
Family size	Household family size	5.873	2.413
Age	Household head age in years	56.83	15.20
Gender	1= Male	0.743	0.437
Education	1= Literate	0.326	0.469
TLU	Herd size in TLU	3.919	3.199
Market distance	Distance to market in minute	82.30	54.79
Shocks(2012-2014)	Number of shocks due to theft, flood, death	0.577	0.826
Irrigation	1=access to irrigation	0.258	0.438
Information	1 if hh had access to TV, radio& mobile	0.417	0.494
Water harvest	1=access to well and ponds	0.0193	0.138
Location	1= highland(>2500masl)	0.0637	0.244
Family labor	Labor used for crop farming in hours	683.60	554.6
HiredL	1=hired labor	0.3880	0.487
Oxen	Number of oxen	1.930	1.045
area	Total cultivated land in tsmdi [c]	4.447	3.138
Family labor	Total adult family labor in man day for crop per season	85.52	69.33
Fertlizer	Total fertilizer used in KG	68.55	49.24
Manure	Total manure used in KG	775.6	1,585
Farm tool	Total monetary value of farm tool in ETB [d]	639.1	1,451

NB: [a] it includes the value of crop, fruit and vegetable production in ETB,
[b] it includes income from Agriculture, off-farm ,transfer and safety net
[c] one Tsmdi is approximated to one-fourth hectare
[d] total monetary value of all farm implements such as plough parts ,hoe, cart, sickle, spade

Table 2: Estimation of Household Labor Allocation to Crop Farming

VARIABLES	(OLS) Ln(Family Labor)	(Level)[a] Family Labor
Real wage(Wage/milk price) in ETB	0.0112***	0.0932**
	(0.00350)	(0.0380)
Ln(WaterD)	-0.0598*	-10.83***
	(0.0360)	(3.377)
Ln(GrazingD)	-0.0929**	-9.655***
	(0.0402)	(2.101)
Ln(FeedD)	-0.0992***	-2.231***
	(0.0287)	(0.487)
Ln (Family size)	0.357***	12.67**
	(0.0659)	(5.375)
Ln (Mark distance)	0.0267	3.624
	(0.0422)	(3.504)
Ln(land area)	0.342***	16.15***
	(0.0462)	(3.905)
Ln(oxen number)	0.142*	3.209
	(0.0732)	(6.109)
Ln(livestock in TLU)	0.0312**	0.131
	(0.0142)	(1.911)
Gender of household head (Male=1)	0.0677	5.637
	(0.0722)	(5.950)
Age of household head (Years)	0.0012	0.0236
	(0.0022)	(0.187)
Household head literacy(Literate=1)	0.0512	-2.453
	(0.0692)	(5.737)
Hired labor (1/0)	-0.151**	14.92**
	(0.0698)	(5.827)
Household home altitude (GPS)	0.0005***	0.0432***
	(0.0001)	(0.0111)
Ln(farm output value)	0.0601***	14.24***
	(0.0149)	(3.010)
Location(1/0)	-0.457***	-33.02**
	(0.164)	(13.12)
Constant	2.299***	-198.5***
	(0.508)	(46.59)
Observations	502	502
R-squared	0.340	0.358

NB: ***, **, *Implies that the estimated parameters are significantly different from zero at 1, 5, and 10% significance level respectively. Figures in parentheses are standard errors; [a] the difference between the first and second column is that the second estimation is based on the level value of family labor and level value of resource scarcity indicators (time taken to reach grazing, water and straw sites measured in hours).

Table 3: OLS Estimation of log Monetary Value of Aggregate Agricultural Production

	Walking Distance		
VARIABLES	lnoutput	lnoutput	lnoutput
Ln(area)	0.278***	0.304***	0.201***
	(0.0595)	(0.0579)	(0.0523)
Ln(manure)	0.0854**	0.0857**	0.0501
	(0.0369)	(0.0363)	(0.0324)
Ln(oxen)	0.228**	0.248***	0.186**
	(0.0973)	(0.0951)	(0.0851)
Ln(fertilizer)	0.145**	0.174***	0.150***
	(0.0665)	(0.0652)	(0.0581)
Ln(seed value)	-0.0992**	-0.0847*	-0.0842**
	(0.0490)	(0.0479)	(0.0428)
Ln(family labor)	0.353***	0.306***	0.197***
	(0.0650)	(0.0641)	(0.0581)
Hired labor(1/0)	0.472***	0.481***	0.307***
	(0.0928)	(0.0907)	(0.0822)
Location(1/0)	-0.493***	-0.453***	-0.544***
	(0.174)	(0.169)	(0.150)
Ln(farm tool)	0.0566**	0.0561**	0.0162
	(0.0254)	(0.0249)	(0.0224)
Ln(mktdistance)	0.0745	0.0808	-0.000798
	(0.0551)	(0.0538)	(0.0485)
Info(1/0)	0.0959	0.0549	0.0264
	(0.0851)	(0.0836)	(0.0746)
Well(1/0)	-0.260	-0.218	-0.0514
	(0.299)	(0.292)	(0.261)
ln(shocks)	-2.160***	-2.091***	-1.932***
	(0.321)	(0.311)	(0.278)
Irrigation(1/0)	0.0627	0.0931	-0.0440
	(0.0980)	(0.0955)	(0.0860)
Education(1/0)	0.284***	0.246***	0.243***
	(0.0904)	(0.0887)	(0.0790)
Ln(WaterD)	-0.155***		
	(0.0475)		
Ln(GrazingD)		-0.279***	
		(0.0471)	
Ln(FeedD)			-0.328***
			(0.0254)
Constant	6.873***	7.383***	9.496***
	(0.500)	(0.492)	(0.476)
Observations	509	508	509
R-squared	0.394	0.423	0.538

NB: ***, **, *Implies that the estimated parameters are significantly different from zero at 1, 5, and 10% significance level respectively
Figures in parentheses are standard errors

Table 4: OLS Estimation of log Monetary Value of Aggregate Agricultural Production

	Shadow Price		
VARIABLES	lnoutput	lnoutput	lnoutput
Ln(area)	0.303***	0.321***	0.281***
	(0.0593)	(0.0593)	(0.0587)
Ln(manure)	0.0848**	0.0834**	0.0752**
	(0.0370)	(0.0368)	(0.0366)
Ln(oxen)	0.208**	0.210**	0.199**
	(0.0978)	(0.0972)	(0.0966)
Ln(fertilizer)	0.146**	0.158**	0.155**
	(0.0666)	(0.0664)	(0.0658)
Ln(seed value)	-0.127**	-0.131***	-0.125**
	(0.0498)	(0.0495)	(0.0488)
Ln(family labor)	0.352***	0.336***	0.330***
	(0.0651)	(0.0650)	(0.0646)
Hired labor(1/0)	0.448***	0.449***	0.430***
	(0.0934)	(0.0928)	(0.0924)
Location(1/0)	-0.502***	-0.508***	-0.562***
	(0.174)	(0.172)	(0.170)
Ln(farm tool)	0.0525**	0.0527**	0.0399
	(0.0255)	(0.0254)	(0.0255)
Ln(mktdistance)	0.0687	0.0725	0.0641
	(0.0553)	(0.0549)	(0.0546)
Information(1/0)	0.0524	0.0234	0.0523
	(0.0862)	(0.0869)	(0.0847)
Well(1/0)	-0.234	-0.206	-0.226
	(0.299)	(0.298)	(0.296)
ln(shocks)	-2.036***	-1.969***	-1.990***
	(0.319)	(0.318)	(0.315)
Irrigation(1/0)	0.0788	0.0960	0.00707
	(0.0979)	(0.0975)	(0.0983)
Education(1/0)	0.267***	0.249***	0.283***
	(0.0906)	(0.0905)	(0.0894)
Ln(ShadowPW)	-0.0739***		
	(0.0240)		
Ln(ShadowPG)		-0.0944***	
		(0.0253)	
Ln(shadowPF)			-0.154***
			(0.0333)
Constant	6.765***	6.904***	7.020***
	(0.492)	(0.493)	(0.486)
Observations	509	509	509
R-squared	0.393	0.398	0.407

NB: ***, **, *Implies that the estimated parameters are significantly different from zero at 1, 5, and 10% significance level respectively
Figures in parentheses are standard errors

Table 5: OLS Estimation of Monetary Value of Aggregate Agricultural Production

	Pool	Male	Female
VARIABLES	Output	Output	Output
Ln(area)	11,713***	11,997**	15,860*
	(4,513)	(5,436)	(8,327)
Ln(manure)	6,845**	6,302*	10,042*
	(3,013)	(3,673)	(5,366)
Ln(oxen)	18,096**	15,453	24,512*
	(8,133)	(10,320)	(13,011)
Ln(fertilizer)	13,430***	13,184**	12,280
	(5,177)	(6,178)	(9,867)
Ln(seed value)	-12,856***	-10,904**	-19,849***
	(4,045)	(4,957)	(7,124)
Ln(family labor)	5,840	2,818	12,615
	(5,392)	(6,505)	(10,242)
Hired labor (1/0)	20,532***	24,190**	7,168
	(7,813)	(9,667)	(13,408)
Location(1/0)	9.682	-164.5	3,603
	(14,608)	(19,080)	(22,392)
Ln(farm tool)	3,531*	4,044	1,909
	(2,128)	(2,626)	(3,774)
Ln(mktdistance)	3,944	8,733	-9,120
	(4,644)	(5,842)	(7,605)
Information(1/0)	-3,657	-3,322	-11,297
	(7,177)	(8,792)	(12,409)
Well(1/0)	17,487	40,239	-41,206
	(25,084)	(32,308)	(37,821)
ln(shocks)	-18,090	-26,396	40,171
	(26,626)	(30,267)	(66,510)
Irrigation(1/0)	-3,655	-2,901	-3,214
	(8,311)	(10,605)	(13,129)
Education(1/0)	4,847	536.2	23,138*
	(7,583)	(9,166)	(13,761)
Water distance (hr)	-170.6***	-179.7**	-157.4*
	(56.30)	(72.29)	(87.17)
Grazing distance (hr)	-188.9***	-207.1***	-141.2*
	(42.52)	(51.94)	(74.03)
Feed distance (hr)	-23.73***	-25.45***	-22.33**
	(6.326)	(8.029)	(10.03)
Constant	-62,098	-71,022	-28,812
	(38,124)	(45,863)	(71,938)
Observations	509	380	129
R-squared	0.266	0.259	0.389

NB: ***, **, *Implies that the estimated parameters are significantly different from zero at 1, 5, and 10% significance level respectively
Figures in parentheses are standard errors

Table 6. Effect of Water, grazing and Feed Scarcity on log Output using Quintile Regression

	log Output				
VARIABLES	q10	q25	q50	q75	q90
Ln(WaterD)	-0.100	-0.163***	-0.176***	-0.180**	-0.129
	(0.0735)	(0.0463)	(0.0500)	(0.0804)	(0.189)
Ln(GrazingD)	-0.215***	-0.204***	-0.230***	-0.374***	-0.453***
	(0.0676)	(0.0408)	(0.0454)	(0.0691)	(0.135)
Ln(FeedD	-0.232***	-0.240***	-0.261***	-0.317***	-0.481***
	(0.0335)	(0.0286)	(0.0250)	(0.0332)	(0.0529)
Ln(ShadowPW)	-0.0884***	-0.0766**	-0.0746**	-0.0670**	-0.0650
	(0.0336)	(0.0361)	(0.0304)	(0.0319)	(0.0427)
Ln(ShadowPG)	-0.113***	-0.0802**	-0.0703***	-0.0932***	-0.109*
	(0.0264)	(0.0321)	(0.0230)	(0.0333)	(0.0589)
Ln(ShadowPF)	-0.126**	-0.126***	-0.149***	-0.229***	-0.272**
	(0.0577)	(0.0299)	(0.0314)	(0.0579)	(0.132)
Observations	509	509	509	509	509

NB: ***, **, *Implies that the estimated parameters are significantly different from zero at 1, 5, and 10% significance level respectively. Figures in parentheses are standard errors

Table 7. The Jacoby Test of Separability with Dependent Variable: log (Shadow Wage/Price)

		Jacoby's Hypothesis: β_0= 0 and β_1 =1	
Ind.variable	Water	OLS	F- Pvalue
Wage		-0. 00121**	0.0000
		(0.0004)	
constant		-2.7995 ***	
		(0.0651)	0.0000
Observations		419	
	Grazing		
wage		-0. 00123**	0.0000
		(0. 0004)	
constant		- 2.84315***	0.0000
		(0. 06514)	
Observations		419	
	Straw		
Straw price		-0.00014*	0.0000
		(0. 00007)	
Constant		-0 .47549***	0.0000
		(0. 05074)	
Observations		403	

NB: ***, **, *Implies that the estimated parameters are significantly different from zero at 1, 5, and 10% significance level respectively. Figures in parentheses are standard errors

Paper 3

Economic Implication of Grazing and Water Resource Scarcity on Households' Welfare and Food Security in Tigrai, Ethiopia

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Abstract: *The scarcity of grazing area and water for animals has a negative effect on household welfare and food security. It can- either affect livestock production directly or indirectly through labor reallocation affecting other sources of income and leisure consumption. In this paper, we explore the link between natural resources scarcity (using distance and shadow price of grazing and water as resource scarcity indicators) and per capita food consumption expenditure (PCFE) as a proxy for welfare and food security. Our data are from 518 sample farmers in Northern Ethiopia. We derive hypotheses from a separable farm household model.*

Our regression results confirmed the theoretical prediction that resource scarcity adversely affect household PCFE (Welfare) and food security in line to the downward spiral hypothesis. As expected, in aggregate, reducing time spent searching for water, grazing and straw leads to an increase in welfare and food security. Precisely, reducing time spent looking for water by 1% leads to an increase in PCFE by 0.13% and food security by 0.06%. Similarly, a 1% decrease in time wastage for searching grazing area increases PCFE and food security by 0.09%, and 0.05% respectively. Likewise, an increment of 0.07% in PCFE and 0.04% in food security is achieved by a 1% reduction in straw transporting time per tripe. The total impact of time spent searching for water, grazing and collecting straw on per PCFE is -0.142 %, -0.102% and -0.092% respectively using distance measure. Thus, reducing reaching time to a water, grazing and straw source by 0.6 hours will increase PCFE by 354 ETB, 254 ETB and 229ETB for the median household.

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Keywords: *Food Consumption; Welfare; Food Security: IV; Tigrai; Ethiopia.*

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1. Introduction

Many studies have established that the rural poor in developing countries are heavily dependent on local natural resources for their livelihoods (e.g., Narain, Gupta and Van't Veld 2008) and that the degradation of resources hurts the poor more (e.g., Khan 2008). The downward spiral hypothesis states that people in poverty are forced to deplete resources to survive, and this environmental depletion further impoverishes them (Ostrom et al. 1999). Land degradation in Sub-Saharan Africa (SSA) remains a substantial problem to spur rural poverty (Bhattacharya and Innes 2006, Tesfa & Mekuriaw 2014). It directly aggravates poverty, by reducing the availability of environmental goods and services and by increasing the labor input needed to seek for such goods in East Africa (Bezabih & Berhane 2014, Lal & Stewart 2010). The World Bank (2012) reported that the cost of environmental degradation is almost 8% of GDP across countries making up 40% of all developing countries.

Livestock production depends on the quantity and quality of feed and water. About 10% of cropland is used to produce crop residues for feeding livestock, and animals in the extensive system need more water per animal compared to the intensive system (Bezabih & Berhane 2014). Increasing scarcity of grazing, water for an animal can be a significant burden to households, as grazing and water are a key factor in livestock production. Thus, the scarcity of these resources may impact agriculture by reallocating factors of production, namely labor from agriculture, food preparation and leisure activities to searching and collecting the resources. Reductions in agricultural output stemming from less labor input are very likely to have detrimental welfare and food security consequences (Cooke 1998, Kumar and Hotchkiss 1988, Alemu, Damte and Deribe 2015). The critical shortage of water and feed for an animal has negative implications for agricultural production and food security, particularly for poor people who rely on agriculture as a source of food and spend considerable time to collecting these resources (Alemu, Damte and Deribe 2015, Yilma et al. 2011).

Poverty and resource degradation thus appear to go hand in hand in SSA. In many studies from Africa, feed and water scarcity are frequently mentioned constraints for animal farming activities (Bezabih & Berhane 2014, Tegegne 2012). In Ethiopia, resource depletion has contributed to the existing problem of food insecurity and is still a real threat to agricultural farming (Bewket 2011). In the study area, environmental depletion has reached a critical stage which, poses a major threat to agriculture production and welfare (Gebregziabher et al. 2009). Grazing and water scarcity may be less problematic in developed countries where substitutes are available but can have a huge impact on household welfare in developing countries like Ethiopia. Households with scarcity may walk longer distances to search and collect these resources, thereby leaving less labor for leisure, food production and preparation (Bezabih & Berhane 2014, Cooke, Köhlin and Hyde 2008).

The literature suggests that as a result of increasing resource scarcity, many households increase the time they spend on collecting them. Overall, the scarcity has negative implications for agricultural production and the food security by diminishing households' food supply and incomes (Cooke, Köhlin and Hyde 2008, Damte, Koch and Mekonnen 2012, Alemu, Damte and Deribe

2015, Tangka and Jabbar 2005). The findings of Cooke (1998), however, revealed that most of the reallocated time for searching and collecting the scarce resources come from leisure before agricultural labor time is reduced. One early analysis conducted by Bandyopadhyay, Shyamsundar and Baccini (2011) also indicates that the amount of biomass negatively affected rural per capita consumption expenditure in Malawi. Grazing and water scarcity in Ethiopia can affect household welfare in different ways. Poor farmers may not have access to alternative feed resources and may increase the time spent on searching for grazing and water and straw collection, reducing time on farming activities, food preparation, leisure or household care. Thus, under situations where markets are imperfect, increasing resource scarcity can force households to reallocate labor, thereby reducing welfare.

While the above studies estimate the effect of resource scarcity on time allocation and time reduction for farming, no study of which I am aware examines the economic effect of grazing and water scarcity on welfare, which is ultimately what policymakers seek to know (Cooke, Köhlin and Hyde 2008, Khan 2008, Tangka and Jabbar 2005). This is of potentially relevant but less well studied. In this study, I am able to estimate the effect of grazing, water and straw scarcity on per capita food consumption expenditure (welfare) and food security using distance and shadow price[17] as a proxy for scarcity indicator of these resources by exploiting household survey from Northern Ethiopia. The analysis is organized around four questions. First, what is the effect of resource scarcity on welfare (PCFE)? Second, how does resource scarcity affect household food security? Third, is this effect stronger among the richest households that are top quantile? And fourth, what is the total welfare effect of the scarcity?

The downward spiral hypothesis states that people in poverty are forced to deplete resources to survive, and this environmental depletion further impoverishes them (Ostrom et al. 1999). In line to this, I hypothesize that the scarcity has a negative effect on households' food security and welfare (PCFE) either by affecting livestock production directly, affecting crop and off-farm income, or indirectly reducing leisure drawing on a separable farm household model. I also hypothesize that the effect of these scarce resources is stronger among the richest households. The empirical evidence suggests that resource scarcity affects household welfare (PCFE) and food security adversely, as predicted by the separable household model and the downward spiral hypothesis. The result from both distance and shadow prices of grazing, water and straw revealed that reducing the time spent for reaching for water for animal, feed and collecting straw leads to an increase in welfare (PCFE) and food security.

This paper builds on the existing literature in a number of respects. In this paper, I contribute to the literature by using a unique dataset to investigate how the distance to or the shadow price of water, grazing and crop residue affects PCFE and food security. I am able to estimate causal

[17] Shadow prices are used as the indicators of resources scarcity. The shadow price of a resource is calculated by multiplying the time spent for searching or collection of a unit of a resource by the off-farm wage rate of that village. See for a similar approach in the work of (Baland et al. 2010; Cooke 1998 and Cooke, Köhlin and Hyde 2008).

relationships with our data because, unlike previous studies, I collected information on the entire set of consumption expenditure, along with the distance to grazing, water and crop residue of each household. Furthermore, unlike the previous studies, I use distance and shadow price as a proxy measure of resource scarcity. This paper joins the relatively scarce, empirical literature on this topic in Africa, one that is dominated by South Asian cases[18].

2. Review of Background and Empirical Literature

The contribution of livestock to the world's food supply, family nutrition, income, employment, soil fertility and transport service contribute to food security and poverty reduction (Randolph et al. 2007; Swanepoel et al. 2010). Livestock also provides a safety net in the form of liquid assets and a strategy of food production diversification (Freeman et al. 2007). The agricultural sector is a cornerstone of the people's economic and social life in Ethiopia. The country, under mixed crop-livestock, owns a significantly large livestock population and its production mainly depends on natural resources such as grazing land, water and own crop residue (Bezabih & Berhane 2014). Despite its large population size, the contribution of livestock production to agriculture is deteriorating (Ilyin 2011). Livestock contributes to 40% of agricultural GDP, excluding the values of draft power, manure and transport services (Asresie and Zemedu 2015). This sector is a key player in increasing water use and water depletion (Steinfeld et al. 2006).

Ethiopian farmers usually experience a very serious seasonal fluctuation in fodder and water availability for the animal. The dependence on these resources implies that scarcity can have a huge impact on household welfare (Bewket 2011, Bezabih & Berhane 2014). Both human and livestock suffer from its shortage. Most of the year, animals have to walk long distances in search of water. Despite the major feed resources are crop residues and natural pasture, their availability is gradually declining as a result of crop expansion, settlement and land degradation (Gebremedhin 2009, Yimer 2005). Hassen et al. (2010) found that a shortage of water and feed are common problems in the dry season as compared to the wet season. The study by Belay et al. (2013) indicated that 100 % and 27% of survey farmers respectively perceived that feed and water shortage were the most important problems of livestock production during the dry season in Ethiopia.

Poor farmers, who are directly dependent on these local natural resources are highly affected by the resource scarcity. Cooke's (1998) result revealed that a reallocation of time away from leisure occurred as environmental goods become scarcer in Nepal. The study of Kumar and Hotchkiss (1988) suggested that deforestation has adverse effects on agricultural production, food consumption and nutrition in Nepal. In addition, the finding of Tangka and Jabbar (2005) in Kenya shows that feed scarcity increases livestock traveling distances in search of feed and water that increase household' time for collection, resulting in lower livestock and crop output which further diminishes households' food and nutrition security. Likewise, Cooke, Köhlin and Hyde (2008)

[18] For a detail review of related empirical studies, see Cooke, Köhlin and Hyde (2008)

found a negative effect of resource scarcity on health, labor burden and agriculture in Nepal. Bhattacharya and Innes (2006) highlighted that forest degradation spurs rural poverty in SSA. According to Bandyopadhyay, Shyamsundar and Baccini (2011) in Malawi, more time spent on scarce fuelwood collection was associated with negative welfare.

Dasgupta (2007) warns that the average per capita consumption level may decline with the degradation of resources. Aggrey et al. (2010) showed that deforestation and degradation were positively linked with poverty in Uganda. The findings of Khan (2008) in Pakistan supported that environmental degradation hurts the poor the most. Baland et al. (2010) indicate that an increase in firewood collection time lowers the living standards of households in Nepal. The study of Aluko (2004) showed that deterioration in the quality of life increases with increasing environmental degradation in Niger. Alemu, Damte and Deribe (2015), in their analysis, show that fuelwood scarcity has a negative impact on time spent on agriculture; however, scarcity of water had no effect on time spent on agriculture in Ethiopia. Likewise, Mekonnen et al. (2017) on their analysis indicated that agricultural productivity decreases with increasing time spent on collecting animal dung but increases with time spent on collecting crop residue. The paper by Boone, Glick and Sahn (2011) suggests that long distance to a water source increase water gathering time in Madagascar.

In spite of the recognized the contributions of the existing studies, none of the above studies examine the effect of grazing and water on welfare and food security (Tangka and Jabbar 2005, Cooke, Köhlin and Hyde 2008). Therefore, this study makes a noteworthy contribution in pointing out the relevance of improving feed and water management for the animal.

3. Theoretical model

To conceptualize the effect of resource scarcity on welfare and food security, I develop a theoretical model within the framework of household utility model following the work of Strauss (1986a) and later used by Faridi & Wadood (2010) which fits into the separable farm household model. The two decisions are assumed to be made separately and recursively in two steps. First, profit is maximized through production decision, and then the utility is maximized through consumption decision. The separation property of the recursive model enables me to separate the estimation of consumption and production sides.

In rural farm households, in which the farmer is engaged in both crop and livestock production activity, total time endowment is divided into three main activities: farm activities, off-farm activities and leisure. However, considering the scarcity of these resources, the total time endowment will further include the 4th, collecting scarce resources activities. It is supposed that the scarcity of resource can affect household well-being either by affecting livestock production directly, affecting crop and off-farm income (via labor re-allocation) or through its direct impact on time for food preparation or leisure consumption (Cooke, Köhlin and Hyde 2008, Alemu, Damte and Deribe 2015).

Rural farm households are characterized by being both producers and consumers of food. Their preferences can be expressed by the following strictly quasi-concave household utility function utility function

$$(1)\ U_i = U(C_i, C_n, C_m, L_l; \Gamma_i)$$

where U_i is a utility function that is twice differentiable, increasing in its arguments, and strictly quasi-concave; C_i and C_n are vectors of home produced food and non-food goods consumed by the ith household; C_m is a market-purchased good consumed and L_l is leisure and $\Gamma_i$is the vector of household socio-demographic variables. Equation (1) leads us to the generalized utility function, which requires that production decision is first made to maximize profit and household maximizes utility using this maximum profit consecutively (Strauss 1986a). The meal production is a function of agricultural goods (Q_i), off-farm income (E) used to purchase meal production inputs such as yeast, salt, oil and stew stuffs, fuel sources such as straw or dung $\left(E_f\right)$ as well as labor days the household would spend on searching for grazing land, water and crop residue (L_c), The production of household goods is also influenced by the vector of household characteristics

(2) $C_i = C(E_f, Q_i, E, L_c; \phi_i)$

The production constraint is specified as:

(3) $F(Q_i, L, L_c, K, A)=0$

Eq. 3 is a typical household implicit production function for food, Q_i produced at home and assumed to be twice differentiable, increasing in outputs, decreasing in inputs, and strictly convex; ; L is the total labor input to the farm; L_c is the time spent on searching for grazing, water and collecting crop residue; K is the fixed capital stock and A is the farm size. The labor time is an important resource, denoted by T, and it includes labor supply for on-farm use L_a, searching and collecting scarce resource L_c and leisure L_l supplied by the household:

(4)$T=L_a + L_c+L_l$

At the same time, the income constraint for the rural household is given by

(5) $P_i(Q_i - C_i) - P_n C_n - P_m C_m - W(L - L_a) + E=0$

P_i is the price of price of food produced; P_iQ_i is a marketed surplus of produced good; P_n is the price of non-food goods; P_m is the price of a market-purchased good; W is the wage rate; $L_a$is total family labor supply for on-farm use; E is non-farm income. Substituting the right-hand side (RHS) of Eq. 4 into 5 yields:

(6) $P_i(Q_i - C_i) - P_n C_n - P_m C_m - W(L - T + L_c+L_l) + E=0$

Expanding and rearranging Eq.6 produces an explicit household income and expenditure:

(7) $P_iQ_i+ WT+ E- WL- WL_c=P_iC_i+P_nC_n+P_mC_m+ WL_l$

The left-hand side of Eq. 7 represents household's full income, which comprises of the value of farm produce P_iQ, the value of time endowment WT, non-farm income E, the value of labor used for farming including the hired labor WL and value of labor spent for searching and collecting scarce resources WL_c. Similarly, the right-hand side of Eq.7 is the household expenditure on food and leisure. The expenditure side includes purchases of its own produce food consumed, P_iC_i; the value of non-food expenditure P_nC_n; the value of market purchase food consumed P_mC_m and purchase of leisure WL_l. The optimization of Eq. 1 yields income and expenditure equation within the separability assumption. At an interior solution the household selects L_c, L_l, L, C_i and C_m to maximize equation (1) subject to equations (7) and (3), which can be best visualized as:

(8) $\mathcal{L}=U(C(E_f, Q_i, E, L_c; \phi), C_n, C_m, L_l; \Gamma) +\lambda\lfloor(P_iQ_i + WT + E - WL - WL_c) - (P_iC_i + P_nC_n + P_mC_m + WL_l)\rfloor +\gamma[F(Q_i, L, L_c, K, A)]$

Based on Straus (1983), it is possible via optimization of Eq. 8 yield production and consumption equations separately as discussed below. The first order conditions are:

(8a) $\frac{d\mathcal{L}}{dL_c} = \frac{dU}{dC}\frac{dC}{dL_c} - \lambda W + \gamma\frac{dF}{dL_c} = 0$

(8b) $\frac{d\mathcal{L}}{dL_l} = \frac{dU}{dL_l} - \lambda W = 0$

(8c) $\frac{d\mathcal{L}}{dL} = \gamma\frac{dF}{dL} - \lambda W = 0$

(8d) $\frac{d\mathcal{L}}{dC_i} = \frac{\partial U}{\partial C_i} - \lambda P_i = 0$

(8e) $\frac{d\mathcal{L}}{dC_m} = \frac{\partial U}{\partial C_m} - \lambda P_m = 0$

(8f) $\frac{d\mathcal{L}}{dC_n} = \frac{\partial U}{\partial C_n} - \lambda P_n = 0$

The recursiveness sense that production decisions are made first and subsequently used in allocating the full income between consumption of goods and leisure is an important property of this model (Strauss 1983).The decision on consumption of the goods is affected by the decision to produce the quantities of goods. It is also assumed that markets exist for both goods and inputs. The production side and consumption-side equations can mathematically and separately be driven following Strauss (1983). To start with production, the demand for inputs (L^*) and output supply (Q^*) is derived in terms of all prices, the wage rate, time for searching and collecting scarce resource, fixed land, and capital as:

(9a) $L^* = l^*(P_i, P_m, P_n, W, L_c, K, A)$

(9b) $Q^* = Q^*(P_i, P_m, P_n, W, L_c, K, A)$

Substituting optimal labor, $L^*$and optimum output Q^* into LHS of Eq. 7 produces optimum income/full income Y^* under the assumption of maximized profit π^* as:

(10a) $Y^* = P_iQ^* + WT + E - WL^* - WL_c$

(10b) $Y^* = WT + \pi^*(P_i, P_m, P_n, W, L_c, K, A) + E$

Where $\pi^*(P_i, P_m, P_n, W, L_c, K, A)$ represents $P_iQ^* - WL^* - WL_c$

The first order conditions of the RHS of Eq.7 give consumption demand function in terms of prices, the wage rate, and income and household's preferences represented by household demographic characteristicsΓ. This relationship can be specified as:

(11) $C_d = c(P_i, P_m, P_n, W, L_c, Y^*(P_i, P_m, P_n, W, L_c, K, A, E); \Gamma)$

The above equation states that household food consumption C_d is mainly influenced by both food and non-food prices, wages, resource scarcity and household income. Referring to household demand for food as a measure of household food security (FS), then C_d is a reduced form of the utility function of Eq. 1, which allows the evaluation of the effects of demographic and economic variables. Food security is approximated by food consumption expenditure[19] in this case,

[19]See for a similar approach in the work of (Smith and Subandoro 2007; Gaiha et al. 2014; Mignouna et al. 2015; Çağlayan and Astar 2012)

The effect of scarce resource on agricultural production is investigated through the production sector and its direct impact on household's utility is explored through the consumption sector. Thus, the total effect which is the sum of the two effects can be further explained using Eq.11. Since time spent for searching grazing or water and collecting straw is one explanatory variable of agricultural output function, the total effect of this variable on per capita food expenditure is:

$$(12)\ \frac{dC_d}{dL_c} = \frac{dC_d}{dY}\frac{dY}{dL_c} + \frac{dC_d}{dL_c}$$

Then, the total effect is simply calculated by taking the slope coefficient of income in the consumption regression multiplied by the coefficient of time allocation in the production estimation, plus the coefficient of time allocation in the consumption regression.

4. Study area and Dataset

The study is conducted in the Tigrai region, the northern part of Ethiopia by randomly selecting 632 sample households. In this region, feed and water deficits start in December, when the natural pastures are at their lowest quantity and the supply of stored crop residues is starting to diminish (Sileshi, Tegegne and Tsadik 2003). Likewise, Gebremedhin (2009) and Yimer (2005) also revealed that natural grazing is diminishing over time due to the high degree of degradation, resulting in high tropical livestock unit (TLU) per km^2 of grazing land. The regional arable land available for crop production contributes about 45% of the animal feed demand. Felleke and Geda (2001) also stated that 73% of the feed is provided from natural grazing, 14% from crop residues, and the remaining 13% from other feed sources. A recent study by Bishu (2014) in Tigrai indicated that there is a water shortage for livestock drinking (34%) and feed shortages (7%). There is also a shortage of labor for livestock management (Tegegne 2012).

This study used cross-sectional data from NMBU-MU[20] Tigrai Rural Household Survey dataset collected in 2015. The data includes a panel of five rounds conducted in 1997/98, 2000/01, 2002/03, 2005/06 and 2014/2015 where the author is involved only in collecting the data for the last round. The primary data used in this paper is adapted from the last, 2014/2015, household survey. Table 1 presents the summary of basic variables of 518 farm households drawn from a total of 632 sample farmers. The need for information regarding livestock activity restricted us to use only 518 livestock owner-farmers for this study.

On the welfare side, the dependent variable is per capita food consumption expenditure (PCFE)[21]. For each household, expenditure profile on the following seven food groups were recorded: (1) staple foods including cereals and pulses, (2) meat, egg and fish, (3) dairy products, (4) fruits and vegetables, (5) fats & oils, (6) sugar and honey, and (7) miscellaneous such as tea, coffee etc. Likewise, the dependent variable on the production side is an aggregate monetary value of all crops produced during the survey production season. An average household has produced an

[20] NMBU-MU refers to the Norwegian University of Life Science-Mekelle University

[21] Thirumarpan (2013) and Asfaw et al. (2012) used consumption expenditure to reflect the socio-economic welfare of household and is a reliable indicator of food accessibility and degree of vulnerability to food insecurity

average agricultural output worth 41,645 ETB and the average total income including sales from agricultural outputs is worth 49,426 ETB. Households, on average, spend approximately about 13571 ETB for food with average PCFE of 2,490 ETB in the year. In order to estimate the food security line for rural households, households' expenditure (PCFE) on food was used. Thus, I construct the food security dependent variable by classifying households into food secure and food insecure using food security index calculated by dividing the individual PCFE to two-third average PCFE of all households[22]. Accordingly, a household is considered food secure if it attains at least two-thirds of the average per capita food expenditure of all households and considered food insecure if it falls below that value. This approach has a wider application in several empirical studies (FAO 2003; Bamou and Mkouonga 2008; Omonona and Agoi 2007).

The results in table 1 showed that 48% of the households were food secure while 52% were food insecure given the two – thirds of the average of all households is 1660 ETB. Feleke et al. (2005) documented about 40% incidence of food insecurity using the timing and amount of maize harvested as a proxy to vulnerability and unsustainability in terms of food insecurity in Ethiopia. Regarding the scarcity indicator, we know that grazing land and water resources are challenging to value because they are not traded and have no market price. Their prices are a shadow price/shadow costs (Magnan, Larson and Taylor 2012) since shadow prices/shadow costs are assumed to better reflect the economic scarcity of environmental goods to a household (Cooke 1998).

There are two methods of scarcity measures: physical measures and economic measures in the literature on resource scarcity. Physical measures, such as the distance from the resource (fuelwood, water, grazing, fodder) or village-level availability of these resources (as applied by Cooke 1998; Kumar, and Hotchkiss 1988; Cooke et al. 2008; Veld et al. 2006; Damte et al. 2012; Mekonnen et al. 2015 and Mekonnen et al. 2017; Hadush 2018). The opportunity cost of the time spent searching or collecting is considered to be a reliable indicator for resource scarcity (Cooke et al. 2008; Damte et al. 2012) than physical measures. The name of opportunity cost is interchangeably known as shadow price or shadow cost of resources and can, therefore be different from the market price (Strauss 1986a).

The opportunity cost is commonly approximated using two ways as demonstrated by (Cooke 1998; Baland et al. 2010; Murphy et al. 2015; Mekonnen et al. 2015; Hadush 2018), who used the wage rate multiplied by the time spent per unit of environmental good collection, as a measure of scarcity, and as the marginal product of labor in resource collection multiplied by the shadow wage (Mekonnen 1999). Due to missing data for the estimation of the economic scarcity, which requires an exclusion restriction, I use only a physical indicators of scarcity. For this reason, as a proxy indicator for scarcity, first, I use walking distance in minutes for a single trip to measure grazing, water per day and crop residue per trip using an approach similar to that used by Palmer and MacGregor (2009).

On average, the households spend 1.25 hours to reach a water source for animal and 1.5 hours to search for communal grazing land daily, with the maximum time reaching up to 6 hours/day for

[22] The same approach is found in the work of Titus & Adetokunbo (2007).

water site and 8 hours/day for grazing land in the data. Besides, the average time spent on collecting crop residue by the households is 9.6 hours per a single trip. Second, following to Cooke (1998), Damte et al. (2012), Baland et al. (2010), Mekonnen et al. (2015) and Hadush (2018), I measure the shadow costs of natural resources (grazing and water) as well as collecting crop residue as the time taken to reach grazing land and water sites or to collect crop residue per its amount collected multiplied by the village adjusted off-farm wage. In this paper, I take the wage rate for those who report working for an off-farm wage in the local labor market and the wages from those who did not report working were missing but imputed following Heckman (1979) two-stage approach as is applied by Cooke (1998). It has been popular to impute wages of non-employed persons from the wage equation, which describes the functional relationship between the wage and personal characteristics such as age, marital status, and place of living, work experience and occupation.

The wage equation is typically modeled within the linear regression model and estimated using the sample of employed persons. However, such an approach, which uses only data on employed persons is criticized by Heckman (1979) and suggested the two-stage model, consisting of a wage equation and a participation equation, in which the latter estimates the probability of a person to be employed vs. non-employed. This has been popular among researchers and widely applied for prediction of wages of non-employed persons for labor supply and estimation of the gender wage gap (see for detail; Labeaga et al. 2008; Breunig and Mercante 2010). In this way, I produce a household specific shadow price of searching for grazing land or water and collecting straw. Table1 reported that the average shadow price for animal watering is about 147 ETB per day which is equivalent to the average daily rural wage rate in the region. On average, the opportunity cost of searching grazing is 205 ETB per day, which is greater than the opportunity cost of water and straw. This is not surprising, because rural farmers usually spend a huge amount of time searching for grazing than for watering. As expected, the shadow price of collecting a residual crop is 12 ETB per trip.

Out of the total sample, 6.4% lives in the highland parts of the region. Nearly 39% of the households report that they have been severely affected by eleven different levels of shocks including, drought, pests, flood, theft, illness and death, loss of job and home damage in the last harvesting season, and 4.25 % of households report having been affected by animal shocks one year before the harvesting season. 74% of the households are male heads with an average age of 57 years and family size of 5.87. Since resources are scarce, high family size may put much more pressure on consumption than it contributes to production. Nearly 32% of the household heads have at least one or more years of education. Thus, it is hypothesized that education is negatively related to consumption value. Around 82% of the households are Orthodox followers while 18% of the households are Muslim households in the study area.

Out of the 518 households in the sample, 61% got assistance either from their relatives or friends and is expected to increase production and consumption (Di Falco Veronesi and Yesuf 2011). More than 40% of household heads site attend media via TV, radio and mobile phone about any development intervention. Hence, it is expected that households with information are more likely to produce more and be food secure. The expected effect on production and consumption is positive (Di Falco Veronesi and Yesuf 2011). In addition, the average livestock endowment of the sample households is 4 TLU which expected to increase food security.

5. Econometric Model Specification

The property of the recursive model enables me to separate the estimation of the consumption and production sectors. With regard to estimation, first, the production function was identified. The parameters from the production side were estimated using General Cobb-Douglas (GCD) production function developed by Diewert (1973). Then, food demand equation (per capita food expenditure) was specified using the utility maximization results of the AHM. Since the objective of the paper is to explore the link between grazing and water resources scarcity and per capita food consumption expenditure (PCFE) as a proxy for welfare and food security, this section mainly deals on the consumption side than production side.

In order to estimate the consumption side, the researcher is forced to approximate welfare by PCFE due to limited data[23]. Assuming that the demand equation from the utility maximization of the recursive household model has a functional form of log-linear, its capability of estimating respective elasticities as its coefficient and modeling nonlinear effects makes it applicable and preferable (Oum 1989). Oum added that the log-linear demand function resembles the demand function obtainable from a Cobb-Douglas utility function with the drawback of invariant estimated elasticities across all data points. The aggregate demand equation per household is estimated for PCFE rather than estimating single demand equations for each product consumed or for each individual member of the household. Following Adewuyi, Mafimisebi and Awe (2009) and Babalola and Isitor (2014), the implicit form of the OLS is given as:

$$(13)\ \ln C_d = \delta + \delta Y_i + \sum_{k=1}^{K} \beta_k \ln X_i + \nu$$

Where $\ln C_d$ is households PCFE; Y_i is a rural farm and off-farm income; X_i for *k=1... K,* includes right-hand consumption side variables and household characteristics; X_1 is aggregate monetary value of crop output; X_2 is herd size in TLU; X_3 is family size; X_4 is gender of the household head with male being equal to 1; X_5refers to the access of information via radio, TV and mobile in binary form; X_6 reflects the agro ecological location of each household measured by GPS but classified as highland if it is 2500 m. a. s. l. and lowland if it is below that; X_7repesents market distance in minutes; X_8 and X_9 correspond to the dummy exposure of animal shock in 2013 and cumulative number of shocks from 2012-2014; $X_{10} = 1$ if the household is reported to be orthodox; $X_{11} = 1$ if the household gets assistance from relatives and friends while X_{12} and X_{13} capture the age of house head in years and total farm income composed of farm income, off-farm income, business transfer and safety net income; The resource scarcity is captured by the walking

[23] Check Asfaw et al. (2012) and Thirumarpan (2013) for similar work. Food expenditure only indicates food availability and accessibility although welfare or food security includes the availability, access, utilization, and stability of nutritious food for an active and healthy life (FAO 1996).

distance to the water source in minutes/day/trip (X_{14}), walking distance to the grazing source in minutes/day/trip (X_{15}) and walking distance to the crop residue site in minutes/trip (X_{16}) per year. ν is an error term.

Since farm and off-farm income is not randomly distributed among rural households, this variable is likely to be endogenous (Hoddinott et al. 2008), which could be caused by omitted variables, measurement error, simultaneity or household unobservable, First, a reverse causality problem might exist, because PCFE at the household level might also influence labor productivity and thus farm productivity. Second, farm and off-farm income might be influenced by household unobservable, which can lead to a correlation with the error term. In the presence of endogeneity, the use of the OLS estimator biases the effect of income (Wooldridge 2009). In order to avoid an endogeneity bias, I adopted a Two-Stage Least Square (2SLS) approach which is the most common instrumental variable estimator (Angrist and Evans 1998) where rural farm income is instrumented by shock exposure and average rainfall of 2003-2014. This is similar to approaches that have been used by Sarris, Savastano and Christiaensen (2006), Hidalgo et al. (2010) and Abdulai and Huffman (2014) in different contexts.

Shock caused by crop theft, illness and death of a household member is expected to affect income and output negatively, thereby reducing food expenditure (Abdulai and Huffman 2014, Dercon, Hoddinott and Woldehanna 2005). The explanation is that farm income is expected to decrease with increasing any shock on crop or animal farming caused by theft or illness of the household. Then its effect on consumption reaches through its effect on farm income. My justification for using rainfall is that the average shortfall of rainfall influence rural farm income without directly influencing the consumption expenditure in the village (Hidalgo et al. 2010). Increasing rainfall is expected to increase farm income directly but consumption indirectly through its effect on income. With this procedure, the structural equation is specified as

$$(14)\quad \ln C_d = \delta + \delta^{iv}\hat{Y} ++ \sum_{k=1}^{K} \beta_k \ln X_i + \varepsilon$$

Where $\ln C_d$ is PCFE, $\hat{Y}$ is the predicted values of the endogenous rural income variables and ε is an error term, β is the parameter coefficient of the vectors of an exogenous variable, X. To obtain income (Y), the first stage regression equation is estimated by OLS based on the following specifications;

$$(15)\quad \ln Y = \alpha + Z'\gamma + X'\beta + \epsilon$$

Where $\ln Y$, is total rural farm income of the household, γ is the parameter coefficients of the vector of the instrumental variables, Z which are assumed to correlate with income (Y) but not with the error term, ε in the structural equation (14). The estimated PCFE of the household, in (14) is now assumed to be unbiased. In order to estimate the effects of water and feed scarcity across the entire distribution of the dependent variables and to document the heterogeneity in the way food consumption respond to these scarcity variations, an alternative quantile regression was used following Koenker and Basset (1978).

6. Per Capita Food Expenditure (PCFE) and Food Security Estimation

The PCFE is analyzed using the demand functions derived from maximized utility subject to budget constraint and technology constraint of farm production and its estimated result is presented in Table 2 and 3 where walking distance and shadow prices are used as scarcity indicators using naive OLS and IV methods. Table 2 and 3, compare results from naive OLS and 2SLS estimates for all variables of interest, namely water, grazing land, and straw site distance. The potential candidate instruments used in the estimation were tested to check if they could pass the necessary requirements for an instrument to be as an instrument. Table 6 reports the test results for all scenarios presented in Table 2 and 3.

The Wu-Hausman F-test with a p-value less than 0.05 rejected the null hypothesis that OLS estimation is consistent or income is exogenous and motivates the use of instruments. Besides, the Sargan chi2 –test fails to reject the null hypothesis that all instruments are uncorrelated with the error term in the structural model or all instruments are valid and this helps to conclude that the instruments pass the over-identification requirement for all estimates. Finally, instruments were also tested if they could pass the second most important criteria that the instrument should be correlated or relevant to the endogenous variable income. To ensure the relevance of instruments, the stock and Yogo (2005) F-test was employed and provided higher value F statistics which is extremely higher than the rule of thumb of at least greater than 10.

The first stage regression results of two-stage least square (2SLS) which are not reported here show that both instruments have a statistical relationship with income and carry the expected sign in all scenarios (Table 2,3). Household income is often a major determinant of expenditure (Babalola and Isitor 2014). Total income of the household, which has a positive coefficient significantly affected PCFE. Column (1, 3, and 5) of Table 2 shows the income effect by estimating the consumption model using OLS estimator. The coefficient of income suggests that a 1% increase in income increases PCFE by around 0.044 %, whereas the 2SLS result display that a one percent increase in total income leads to 0.059 percent increase in PCFE in all estimates. Because, as the income level of the household increases, the household purchasing power increases.

It turns out that this naive ordinary estimate grossly underestimates the income effect compared to effects from the IV-2SLS estimate. This implies that estimating the model using OLS is not the correct approach and ignoring these differences would bias the income effect. The findings of Babalola and Isitor (2014), Njimanted (2006), and Thirumarpan (2013) also confirm that household income is one of the key determinants of food expenditure and food security in rural areas. I also report that farm output significantly affects household food consumption. The elasticity of PCFE with respect to the gross crop value equals to 0.063% for IV in the water scarcity estimates. Similar effects are found in the grazing and feed estimates presented in Table 2, columns 3-6. This is in line with Sarris, Savastano and Christiaensen (2006) who found that agricultural productivity significantly affects PCFE in Ethiopia. The coefficient's sign and statistical significance show that livestock ownership is positively correlated with PCEF, suggesting that farmers with high herd size have a higher food consumption expenditure. Studies by Dercon, Hoddinott and Woldehanna (2005) in Ethiopia and Sarris, Savastano and Christiaensen (2006) in Tanzania found a similar result.

Another significant variable is household size, leading to 0.36% decrease in PCFE for 1% increase in the number of member of the household. This result is in line with the findings of (Bezu et al. 2014, Dercon, Hoddinott and Woldehanna 2005) in Ethiopia and Sarris et al. (2006) in Tanzania. A household with a male head has a disadvantage of 13.6% decrement in PCFE against the findings of Dercon, Hoddinott and Woldehanna (2005) in Ethiopia. Individual farmers experiencing an animal shock at least once in the previous year have 39.9%, 46% and 45.7% lower PCFE for the three cases taking the estimated value of IV in Table 2. In line to this, Dercon (2004) found that a livestock shock negatively affects PCFE in rural Ethiopia.

The coefficient of religion is 0.146 and is statistically significant, implying that orthodox households have 14.6% higher PCFE than Muslim group referring to the IV estimate which is opposite to the result of Oldiges (2012) in India. The negative and significant sign of network shows that individuals who got social supports have 17.2 % less PCFE, implying that supports from relatives or friends are not adequate enough to cover food expenditure for the recipient households. A similar result was found by Sarris, Savastano and Christiaensen (2006). Other insignificant variables are proximity to market (positive), information (positive) and the age of the household head (negative) in line with the study of Matchaya & Chilonda (2012) in Malawi.

The main interest of this paper is to explore how time spent for animal feed and water searching directly affect PCFE and our result is in line with the downward spiral hypothesis (Ostrom et al. 1999). Using the distance indicator in Table 2, time spent looking for water and grazing land has resulted in a negative sign and it is found to be an important factor of PCFE. A one percent increase in minutes traveled to reach water and grazing land leads to a 0.131% and 0.088% decrease in PCFE respectively using IV. In addition, a one percent increase in minutes traveled to collect crop residue leads to 0.072% decrease in PCFE. Likewise, my results from the shadow price (Table 3) indicate that scarcity of resources has an important impact on the food demand, with the expected result that an increase in the shadow price of water, grazing and crop residue by one percent reduces PCFE by 0.053%, 0.067% and 0.044% respectively. This implies that the scarcity has a negative effect on households' PCFE either by affecting livestock production directly, affecting crop or off-farm income via labor reallocation or through its direct impact on time leisure consumption.

This result agrees with the finding of Bandyopadhyay, Shyamsundar and Baccini (2011) whose result revealed that the scarcity of biomass negatively affected rural PCFE in Malawi. Baland et al. (2010) also showed that an increase in firewood collection time by one hour/day is equivalent to an income loss of about 1% in Nepal. Bhattacharya and Innes (2006) highlighted that forest degradation spurs rural poverty in Sub-Saharan Africa. This supports the argument by (Chopra et al. 2007; Cooke, Köhlin and Hyde 2008; Kumar and Hotchkiss 1988; Tangka & Jabbar 2005), whose study concluded that feed and water scarcity reduces livestock, crop, and non-farm productivity as well as access to food. It further results in food insecurity and low human welfare by traveling long distance with an animal in search of feed and water in less developing countries.

Estimation of food security is presented in Table 4; the model had about 38 % prediction power as compared to 48 % observed probability. The negative significant relationship between the shadow prices and the household food security implies that household who spend more time on searching for water, grazing and straw are more likely to be food insecure than their counterparts with nearer distance. The coefficients from marginal effect indicated that increasing the shadow prices of water, grazing and crop residue reduces the probability of food security by 0.06, 0.05 and 0.04 percent respectively, supporting the arguments forwarded by Cooke, Köhlin and Hyde (2008) and Alemu, Damte and Deribe (2015). The results further show that the probability of food security increases significantly and consistently with farm output, total income, and religion in favor of Ogundari (2017) but declines with family and herd size, supporting the results from Feleke et al. (2005).

An alternative is to estimate quantile regressions on food expenditure in order to capture the effects of these scarce variables across the entire distribution of the dependent of the variable. Quantile regression is a method of estimating functional relationships between variables for all portions of a distribution function (Koenker and Basset 1978). The hypothesis that the impact of feed and water scarcity strongly increases from the bottom to the top quartile is tested using this quantile regression and results are displayed in Table 5. The elasticity values associated with a 1% change in distance to a grazing land on food production range from -0.0996% for the forth quantile to -0.171% of top quartile with a median value of -0.100% in Table 5. The effect of a 1% increase in distance to crop residue source brings about a 0.069% reduction in food expenditure only for the top category while the effect of water is 0.064% at the median value. This analysis is relevant not only from the perspective of econometric correctness but also for the purposes of policy. This is an evidence that treating all quantiles as one and hence estimating only one coefficient such as in OLS would be misleading both for policy and inference.

7. Total Effect of Feed and Water Scarcity on Food Security

This section discusses the total effect of water and feed scarcity for an animal on total welfare effect. Based on Eq.12, the total effect is simply calculated by taking the slope coefficient of income in the consumption regression multiplied by the coefficient of time allocation in the production estimation, plus the coefficient of time allocation in the consumption regression that is the total effect of grazing scarcity is the slope coefficient of income $\left(\frac{dC_d}{dY}\right)$ in the consumption regression multiplied by the coefficient of time spent for searching grazing in the production estimation $\left(\frac{dY}{dL_c}\right)$ plus the coefficient of time spent for searching grazing in the consumption regression $\left(\frac{dC_d}{dL_c}\right)$; the total effect of water scarcity is the slope coefficient of income $\left(\frac{dC_d}{dY}\right)$ in the consumption regression multiplied by the coefficient of time spent for searching water in the production estimation $\left(\frac{dY}{dL_c}\right)$ plus the coefficient of time spent for searching water in the consumption regression $\left(\frac{dC_d}{dL_c}\right)$ and the total effect of straw scarcity is the slope coefficient of income $\left(\frac{dC_d}{dY}\right)$ in the consumption regression multiplied by the coefficient of time spent for collecting straw in the production estimation $\left(\frac{dY}{dL_c}\right)$ plus the coefficient of time spent for collecting straw in the consumption regression $\left(\frac{dC_d}{dL_c}\right)$. However, the coefficient of time spent on searching grazing and water or for collecting straw in the production estimation $\left(\frac{dY}{dL_c}\right)$ is not available here. It is available upon request.

Based on Table 7, the total impact of time spent searching for water, feed and collecting straw on per PCFE is -0.142 %, -0.102% and -0.092% respectively using distance measure. This implies that for a one percent increase in hours traveled to a water, grazing and straw source, PCFE decreases by 0.142%, 0.102%, and 0.092% respectively. If the median household in this data spends about 60 minutes daily to look for water and feed source and has PCFE 2490 ETB, decreasing traveling time by an hour to a water, grazing and straw source by 0.6 hours/day will increase PCFE by 354 (2490*0.142) ETB, 254 (2490*0.102) ETB and 229 (2490*0.092) ETB respectively for the median household using panel A distance value (Table 7).

8. Conclusion and Suggestion

The scarcity of grazing and water for an animal has negative effects on household's welfare and food security either by affecting livestock production directly, affecting crop or off-farm income via labor reallocation or through its direct impact on time leisure consumption. My research questions focus on the relationship between natural resources scarcity and PCFE (welfare) and food security. In this paper, I have explored this effects using distance and shadow price as resource scarcity indicators in Northern Ethiopia based on 518 sample farmers. To address my research first objective, I employed the IV 2SLS estimation and the second question is addressed by estimating a probit model for food security. The descriptive result shows that about 48% of the households were food secure while 52% were food insecure given the two – thirds of the average of all household's PCFE is 1660 ETB.

My results confirmed the theoretical prediction that resources scarcity affects households' welfare and food security adversely as predicted by the downward spiral hypothesis (Ostrom et al., 1999). The results in this paper provide an interesting picture of smallholders in Ethiopia and hint at several areas that could be important for improving food security and welfare in general. As expected, it appears that time spent looking for water and feed has a significant and negative effect on PCFE and food security. In aggregate, reducing time spent looking for water by one percent leads to an increase in PCFE by 0.131 percent and food security by 0.0594 percent. Similarly, a one percent decrease in time wastage for searching grazing land increases PCFE and aggregate food security by 0.088 percent, and 0.053 percent respectively. Likewise, an increment of 0.0716 percent in PCFE and 0.0418 percent in food security is achieved by a one percent reduction in crop residue transporting time per tripe.

The total impact of time spent searching for water, feed and collecting straw on PCFE is -0.142%, -0.102% and -0.092% respectively using distance measure in Table 7. The median household in these data spends about 60 minutes to look for water and feed source and have per capita food consumption expenditure of 2490 ETB. For the median household, decreasing traveling time by an hour to water, grazing and straw feed source by 0.6 (60/100) hours will increase total welfare by 354 (2490*0.142) ETB, 254 (2490*0.102) ETB and 229 (2490*0.092) ETB respectively.

Depending on results from the quantile regression, the effect of water and feed scarcity is not uniform across the food income group, implying that its negative effect strongly increases from the bottom (poor) to the top (rich) quantile. For instance, the elasticity values associated with a 1% change in distance to a grazing land on food production ranges from -0.0996% for the fourth quantile to -0.171% of the top quartile with a median value of -0.100%. The effect of a 1% increase in distance to crop residue source brings about a 0.069% reduction in food expenditure only for the top category while the effect of water is 0.064% at the median value. This analysis is relevant for the purposes of policy. If coefficients for a policy variable differ in different quantiles of the output variable, it implies that a policy change seeking to address issues of resource scarcity will have different effects on different households based on their position on the distribution of the food income variable.

In general, this study can be helpful for policymakers working to alleviate animal water and feed problems in Ethiopia to justify their actions with empirical results. The findings play a great role in the understanding of the linkage between welfare, food security, and environmental resources such as grazing and water scarcity. Three areas of policy intervention can be emerged as relevant. The first involves policies and institutions that facilitate easier access to animal water tap by advocating on emergency relief grounds. The second area of policy intervention involves the introduction of more efficient animal feed management strategies such as stall feeding and rotational grazing with the help of improved cow adoption that can improve cattle production and reduce land degradation. A policy that sought to increase household food consumption would greatly impact the highest quantile more than those who are in the lowest quantile of food production distribution.

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Table 1. Descriptive and Summary Statistics

		N=518	
VARIABLES	Description	Mean	SD
Dependent Variables			
FE	Monetary value of food expenditure (ETB)	13571.4	19717.4
PCFE	Monetary value of per capita food expenditure(ETB)	2,490	3,722
Output	Monetary value of crop production(ETB)[a]	41,645	87,517
FSI	Food Security Index[c]	0.4826	0.5001
Independent Variables			
ShadowPW	Shadow price of water, ETB/single trip	147.6	204.9
ShadowPG	Shadow price of grazing, ETB/single trip	205.0	282.0
shadowPF	Shadow price of crop residue, ETB/ donkey load/season	12.52	18.96
WaterD	Distance to animal water source in minute per day	74.85	65.54
GrazingD	Time spent looking for grazing land in minute per day	91.12	83.44
FeedD	Time to transport crop reside in minute per trip per year	576.55	557.87
Income	Monetary value of total income(ETB)[b]	49521	92,642
Family size	Household family size (count)	5.873	2.413
Age	Household head age (years)	56.83	15.20
Gender	1 = Male	0.743	0.437
Education	1=literate	0.326	0.469
TLU	Herd size in Tropical Livestock Unit	3.919	3.199
MarketD	Market distance in walking minute	82.30	54.79
Shocks(2012-2014)	Number of shocks due to theft, flood, death	0.577	0.826
Information	1=access to TV, radio & mobile	0.417	0.494
Location	1= highland(>2500masl)	0.0637	0.244
Network	1= support from relatives &friends	0.610	0.488
Religion	1 =orthodox & 0 Muslim	0.824	0.381
Ashock13	1=face animal shock in 2013	0.0425	0.202

NB: [a] it includes crop, fruit and vegetable production, and ETB refers to Ethiopian currency in which 1USD~ 23 ETB during the study period

[b] it includes income from Agriculture, off-farm, business transfer and safety net

[c] a household is considered food secure if it attains at least two – thirds of the average PCFE of all households and considered food insecure if it falls below that value.

Table 2: IV Estimation of log Per Capita Food Expenditure using Walking Distance

VARIABLS	(OLS) lnPCFE	(IV) lnPCFE	(OLS) lnPCFE	(IV) lnPCFE	(OLS) lnPCFE	(IV) lnPCFE
Ln(output)	0.094***	0.063***	0.091***	0.063***	0.099***	0.069***
	(0.012)	(0.016)	(0.013)	(0.016)	(0.012)	(0.016)
Ln(livestock)	0.034***	0.029**	0.0334**	0.029**	0.035***	0.031**
	(0.013)	(0.013)	(0.013)	(0.013)	(0.0130)	(0.014)
Ln(Family size)	-0.385***	-0.362***	-0.397***	-0.374***	-0.388***	-0.366***
	(0.053)	(0.055)	(0.054)	(0.055)	(0.053)	(0.055)
Gender(1/0)	-0.119**	-0.136**	-0.099*	-0.114*	-0.115*	-0.133**
	(0.059)	(0.061)	(0.0590)	(0.061)	(0.059)	(0.061)
Information (1/0)	0.059	0.041	0.045	0.029	0.0487	0.029
	(0.054)	(0.056)	(0.055)	(0.056)	(0.054)	(0.056)
Location (1/0)	-0.041	-0.052	-0.114	-0.129	-0.149	-0.169
	(0.140)	(0.144)	(0.140)	(0.143)	(0.141)	(0.145)
Ln(marketD)	0.003	0.017	0.003	0.017	0.002	0.015
	(0.034)	(0.035)	(0.034)	(0.035)	(0.034)	(0.035)
Ashock13(1/0)	-0.489**	-0.399**	-0.550***	-0.463**	-0.540***	-0.457**
	(0.191)	(0.199)	(0.192)	(0.200)	(0.193)	(0.200)
Ln(shocks)	0.212	0.345*	0.307	0.434**	0.267	0.401*
	(0.198)	(0.209)	(0.199)	(0.210)	(0.200)	(0.210)
Religion (1/0)	0.121*	0.146**	0.101	0.124*	0.115	0.140*
	(0.070)	(0.073)	(0.071)	(0.073)	(0.071)	(0.073)
Network (1/0)	-0.083	-0.172***	-0.076	-0.158**	-0.073	-0.159**
	(0.055)	(0.065)	(0.056)	(0.065)	(0.056)	(0.065)
Age(years(	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Ln(income)	0.044***	0.057***	0.043***	0.055***	0.044***	0.056***
	(0.002)	(0.005)	(0.002)	(0.005)	(0.002)	(0.005)
Ln(WaterD)	-0.122***	-0.131***				
	(0.031)	(0.032)				
Ln(GrazingD)			-0.100***	-0.089**		
			(0.034)	(0.035)		
Ln(FeedD)					-0.064***	-0.072***
					(0.024)	(0.025)
Constant	6.018***	5.970***	6.046***	5.898***	5.917***	5.880***
	(0.291)	(0.300)	(0.318)	(0.330)	(0.305)	(0.319)
R-squared	0.710	0.683	0.705	0.681	0.705	0.679
First stage						
Shock		-20.132***		-20.122***		-20.140***
		(2.169)		(2.172)		(2.169)
Rainfall		0.166**		0.161**		0.166**
		(0.057)		(0.058)		(0.057)
Observation	496	496	496	496	496	496

P- Values are for slopes; ***P<0.01; **P<0.05and *P<0.10= Significant at 1%, 5% and 10% probability level respectively

Table 3: IV Estimation of log Per Capita Food Expenditure using Shadow Prices

VARIABLS	(OLS) lnPCFE	(IV) lnPCFE	(OLS) lnPCFE	(IV) lnPCFE	(OLS) lnPCFE	(IV) lnPCFE
Ln(output)	0.099***	0.069***	0.098***	0.068***	0.084***	0.059***
	(0.012)	(0.016)	(0.012)	(0.016)	(0.013)	(0.017)
Ln(livestock)	0.038***	0.034**	0.037***	0.033**	0.036***	0.033**
	(0.013)	(0.0134)	(0.013)	(0.012)	(0.013)	(0.013)
Ln(Family size)	-0.388***	-0.366***	-0.380***	-0.356***	-0.379***	-0.360***
	(0.054)	(0.056)	(0.054)	(0.056)	(0.053)	(0.055)
Gender(1/0)	-0.103*	-0.118*	-0.085	-0.105*	-0.113*	-0.125**
	(0.059)	(0.061)	(0.059)	(0.062)	(0.059)	(0.061)
Information(1/0)	0.054	0.036	0.040	0.025	0.041	0.027
	(0.055)	(0.056)	(0.055)	(0.057)	(0.054)	(0.056)
Location(1/0)	-0.048	-0.063	-0.0567	-0.091	-0.126	-0.139
	(0.145)	(0.149)	(0.141)	(0.146)	(0.140)	(0.143)
Ln(MarketD)	0.004	0.0173	0.002	0.015	0.003	0.016
	(0.034)	(0.035)	(0.034)	(0.036)	(0.034)	(0.035)
Ashock13(1/0)	-0.494**	-0.408**	-0.526***	-0.431**	-0.505***	-0.426**
	(0.193)	(0.201)	(0.192)	(0.201)	(0.192)	(0.198)
Ln(Shocks)	0.220	0.354*	0.241	0.396*	0.247	0.378*
	(0.203)	(0.214)	(0.199)	(0.212)	(0.199)	(0.210)
Religion(1/0)	0.119*	0.143*	0.095	0.122*	0.111	0.132*
	(0.071)	(0.074)	(0.071)	(0.074)	(0.070)	(0.072)
Network(1/0)	-0.084	-0.170***	-0.0833	-0.167***	-0.068	-0.147**
	(0.057)	(0.066)	(0.056)	(0.065)	(0.0557)	(0.065)
Age(years(	-0.001	-0.002	-0.001	-0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Ln(Income)	0.044***	0.056***	0.043***	0.056***	0.043***	0.055***
	(0.002)	(0.005)	(0.002)	(0.005)	(0.002)	(0.005)
Ln(ShadowPW)	-0.0520*	-0.053*				
	(0.029)	(0.030)				
Ln(ShadowPG)			-0.097***	-0.067**		
			(0.029)	(0.031)		
Ln(ShadowPF)					-0.053***	-0.0441**
					(0.017)	(0.018)
Constant	5.753***	5.672***	6.052***	5.785***	5.835***	5.702***
	(0.300)	(0.309)	(0.308)	(0.331)	(0.283)	(0.294)
R-squared	0.702	0.676	0.705	0.675	0.706	0.684
First stage						
Average rainfall		0.167***		0.1459***		0.163***
		(0.057)		(0. 058)		(0.058)
Shock		-20.156***		-19.932***		-20.01***
		(2.184)		(2.172)		(2.177)
Observation	496	496	496	496	496	496

NB: P- Values are for slopes; ***P<0.01; **P<0.05and *P<0.10= Significant at 1%, 5% and 10% probability level respectively.

Table 4. Probit Estimation of Food Security using Shadow Prices

VARIABLS	(ME) FSI	(ME) FSI	(ME) FSI
Ln(output)	0.028**	0.032**	0.015
	(0.013)	(0.014)	(0.015)
Ln(livestock)	-0.026**	-0.024*	-0.027**
	(0.012)	(0.012)	(0.012)
Ln(Family size)	-0.203***	-0.202***	-0.206***
	(0.059)	(0.059)	(0.059)
Gender(1/0)	-0.088	-0.059	-0.085
	(0.067)	(0.067)	(0.067)
Information(1/0)	0.063	0.036	0.051
	(0.058)	(0.059)	(0.059)
Location(1/0)	-0.096	-0.126	-0.169
	(0.146)	(0.134)	(0.124)
Ln(marketD)	-0.045	-0.054	-0.041
	(0.0376)	(0.038)	(0.037)
Shock13(1/0)	-0.138	-0.155	-0.151
	(0.197)	(0.187)	(0.189)
Ln(shocks)	0.355	0.404*	0.395*
	(0.240)	(0.219)	(0.224)
Religion(1/0)	0.147**	0.135**	0.135**
	(0.065)	(0.065)	(0.065)
Network(1/0)	-0.070	-0.042	-0.048
	(0.065)	(0.064)	(0.064)
Age(years(	-0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)
Ln(income)	0.033***	0.032***	0.032***
	(0.003)	(0.003)	(0.003)
Ln(ShadowPW)	-0.059*		
	(0.033)		
Ln(ShadowPG)		-0.053*	
		(0.031)	
Ln(ShadowPF)			-0.042**
			(0.019)
Observed Probability	0.482	0.479	0.482
Predicted probability	0.380	0.372	0.379
Pseudo R2	0.438	0.440	0.441
Observation	514	514	514

P- Values are for slopes; ***P<0.01; **P<0.05and *P<0.10= Significant at 1%, 5% and 10% probability level respectively

Table 5. Effect of Water, grazing and Feed Scarcity on log PCFE using Quintile Regression

VARIABLES	(PCFE) q10	(PCFE) q25	(PCFE) q50	(PCFE) q75	(PCFE) q90
Ln(ShadowPW)	-0.0021	-0.010	-0.064**	-0.034	-0.029
	(0.055)	(0.029)	(0.026)	(0.027)	(0.046)
Ln(ShadowPG)	-0.061	-0.035	-0.100***	-0.099***	-0.171***
	(0.041)	(0.027)	(0.031)	(0.029)	(0.049)
Ln(ShadowPF)	-0.041	-0.004	-0.009	-0.019	-0.069***
	(0.037)	(0.025)	(0.018)	(0.017)	(0.026)
Observations	496	496	496	496	496

P- Values are for slopes; ***P<0.01; **P<0.05and *P<0.10= Significant at 1%, 5% and 10% probability level respectively

Table 6. Instrumental Variables Tests

Estimates	Endogeneity	validity	Relevance
	Criteria		
	Wu-Hausman (P-value)	**Sargan(P-value)**	***Stock and Yogo*, F-value**
Water scarcity Model	(0.0008)	(0.5562)	42.28
Gazing scarcity Model	(0.0011)	(0.5236)	42.27
Straw scarcity Model	(0.0013)	(0.5417)	42.56

Table 7. Aggregate Effect of Resource Scarcity on Output, Food Expenditure, and Food Security

Estimates	Effect on output (Y)	Effect on PCFE	Total effect
Panel A using distance value in in minute per single trip	$\frac{dY}{dT}$	$\frac{dPCFE}{dT}$	$\frac{dPCFE}{dY}\frac{dY}{dT}+\frac{dPCFE}{dT}$
Water scarcity (T_w)	-0.155	-0.133	-0.142
Grazing scarcity (T_f)	-0.279	-0.086	-.102
Straw scarcity (T_t)	-0. 328	-.0731	-.092
Panel B using shadow price in ETB/single trip			
Water scarcity (T_w)	-0.074	-0.0529	-.057
Grazing scarcity (T_f)	-0.094	-0.0627	-.068
Straw Scarcity (T_t)	-0.154	-0.0421	-.051

Paper 4

Analyzing Production Risk and Patience on Farmers' Use and Choice of Improved Livestock Feeding Practice in Tigrai, Ethiopia?

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Abstract: *A number of improved feeding practices such as stall feeding, rotational grazing, and tethering can help increase livestock productivity in Ethiopia. The main aim of this paper is to determine what factors affect the adoption of such improved feeding practice; i.e. Stall Feeding (SF) and the choice of animal or season for its application. A control function based on the bivariate probit model was estimated using observations from 367 rural farmers in Northern Ethiopia.*

Production risk, the frequency of shock and discount rate are found to be key determinants. As expected, the discount rate was found to be endogenous and instrumental variables for it was statistically significant and bear the expected signs. The results from bivariate model revealed that the expected yield positively influenced SF adoption decision and its full-year application while yield variability and risk of yield failure had a negative effect on SF adoption decision and its full-year application. Likewise, previous animal shocks and time preference positively contribute to SF adoption. The major contribution of this paper is its explicit treatment of production risk, shock and time preference in the decision to adopt and apply SF. Expected benefits that the farmer can derive from low production risk due to SF adoption should be included in the promotion agenda of SF practice. The implication is that intervention that reduces the variance of return and exposure to downside risk are some desirable in the adoption and choice decision.

Key Words: ***Stall-feeding adoption and application; production risk; shock: discount rate control function bivariate model: Ethiopia,***

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1. Introduction

In sub–Saharan Africa (SSA), livestock production plays multiple fundamental roles for rural households when crop farming becomes variable due to climate change (Cecchi et al., 2010). These roles can be illustrated by a few statistical numbers. Agriculture accounts for about 43% of the gross domestic product and over 60% of exports (Odame et al., 2013) in SSA. In Ethiopia, livestock is central to the livelihood of the rural poor by contributing about 12–16% of the total GDP, and 40% of total agricultural GDP excluding the values of draught power, transport and manure (Halderman, 2004). Livestock production accounts for nearly 80% of farmer income in the country and ownership of livestock denotes social status during the cultural marriage (Ilyin, 2011). In addition, it provides 14 million tons of manure annually mainly for fuel and organic fertilizer uses. The value of animal draught power input into arable production is about 26.4% of the value of annual crop production (FAO, 2005).

Livestock production in Ethiopia is, however, low in productivity in terms of milk and meat production per animal (MoA, 2012; World Bank, 2007). This is due to among others: i) fluctuating weather conditions which result in fodder and grass, either not available in sufficient quantities or are of poor nutritional quality when they are available; ii) poor availability of feed and fodder that affect livestock productivity; iii) animal diseases infection that is responsible for low livestock production in the region (Amudavi et al., 2009); and iv) low technology practices and poor marketing (Gebremedhin, 2009; Benin et al., 2006).

Livestock losses resulting from climate change seriously affect livestock production and disrupt every aspect of the livelihoods of households (Kabubo-Mariara, 2009). Over 12 million people have suffered from the adverse effects of climate change on earnings from livestock production in the SSA region (Armstrong et al., 2013). Most countries in East Africa including Ethiopia are not adequately prepared for the aftereffects of disasters which occur frequently causing livestock loss. Severe droughts (1984, 2000, 2003 and 2011) in Ethiopia resulted in heavy livestock losses and production failure (Benin et al., 2006). This is further aggravated by land degradation resulting from overgrazing, reducing the contribution from livestock and pose a threat to food security in the region (Ilyin, 2011).

In response to this, risk-reducing practices such as rotational grazing, zero grazing (ZG), tethering, stall-feeding (SF)[25)] along with the improved cows have been proposed in the region as potential options to alleviate the animal feed shortage, reduce land degradation and improve

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[25)] Stall Feeding (SF) adoption in this paper is defined as the practice of feeding some or all animals in an open homestead land. Full Stall Feeding (FSF) adoption is the practice of stall feeding some or all animals in a full-year round and Seasonal Stall Feeding (SSF) is for at least one season of the year. SF can be applied in a single season or in a full year term. It is also possible that a farmer can allocate his milking cows to SF while his oxen to free grazing (Lenaerts, 2013). Different sources of feds including straw, green grass, stall, brewery, salt, own or purchased supplementary feeds and modern feeds such as Sespaina sespan and elephant grasses etc.… are used.

livestock production by minimizing production risks caused by theft, flood, disease and cattle fighting due to free grazing (FAO, 2007; De Cao et al., 2013; Bishu, 2014; Lenaerts, 2013). Among these technologies, SF, where animals are kept indoors and fed in a cut and carry system is suggested as an alternative climate-smart strategy. This is because SF protects livestock from diseases and deaths by avoiding free livestock contact, cattle fighting, flood, theft, predation and exposure to a high temperature in free grazing system (USAID, 2013). SF is an ideal way to maintain breed cows, address land degradation of grazing land and improve fodder and milk productivity (Ilyin, 2011; Bishu, 2014). An earlier study in Uganda confirmed that SF is economically viable and ecologically sustainable (Garcia et al*.,* 2008). Although the introduction of SF is believed to be a risk-reducing and feed saving technology, the adoption rate has remained slow and low in the region (Lenaerts, 2013; FAO, 2007).

The adoption of new technologies always involves a degree of risk and uncertainty concerning the effect of this input on the distribution of farmers' profits. Uncertainty associated with the adoption of new technology includes the perceived riskiness of future farm yield after adoption and production uncertainty related to farming itself (Koundouri et al., 2006). A proper analysis of farmers' production decisions is supposed to account for production risk and farmer's risk attitude (Czekaj & Henningsen, 2013). Production risk affects new technology adoption and that farmers choose to adopt the new technology in order to hedge this production risk (Koundouri et al., 2006). A risk-averse farmer may hedge against weather risk or reduce weather-related risk by adopting risk-reducing technologies (Antle, 1987; De Pintoa et al., 2013; Kahan, 2013).

The standard economic theory also stated that the tendency to adopt new practice is driven by the individual time preferences of the decision makers (Duflo et al., 2011; Le Cotty et al., 2014; Tucker, 2006). Despite its apparent importance, there is little supporting evidence for its role in the technology adoption (Sunding et al., 2001; Chavas et al., 2010). A recent study by Holden and Westberg (2016) and Bezabih et al. (2012) pointed out that shock plays a vital role in technology adoption but got less attention. Despite their relevance, production risk, shock and time preference are, rarely, used in agricultural adoption studies, particularly in the case of cattle farming and East Africa (Liu and Huang, 2013; Just et al., 2010; Holden & Quiggin, 2017).

To the best of the author's knowledge, it is not known a priory whether production risk itself or the uncertainty associated with the new technology may lead to sub-optimally slow diffusion of SF practice in the region. This paper, therefore, seeks to examine whether livestock farmers in North Ethiopia are facing production risks and have a coping strategy that they opted for in order to curb the negative effects of these risks. Thus, the main objective of this paper is not to analyze production per se but the effect of production risk, shock exposure and time preference on SF and animal/seasonal choice. This is done by adapting moment-based approach (Antle, 1987) for estimating production risk. A control function based on the bivariate model was used for the joint decision of SF adoption and animal/season selection using a dataset of 518 farmers sampled during the 2014/2015 farming season in Tigrai.

The analysis is organized around four questions. First, does production risk induce or reduce stall feeding adoption and its full-year application? Second, how does previous frequency of animal shock impacts stall feeding adoption and its full year application? Third, are farmers with high discount rates less likely to adopt stall feeding and apply it in a full-year term? Fourth, which animal is the choice of smallholder farmers for stall feeding? Using the theoretical framework suggested by Antle (1987) and Koundouri et al. (2006), the author shows production risk to be the main determinants of SF adoption using estimated moments of the value of milk production. First, farmers are expected to be motivated to adopt SF whenever it promises them higher return (i.e. the first moment-predicted mean is positively related to adoption). Second, output variability (as measured by the second moment) discourages farmers from applying SF. Third, higher probability of output failure (downside risk), as measured by skewness of yield, increases the farmers' chance of adoption or decreases adoption when farmers view SF as risk-reducing or as risk-increasing. Fourth, animal shocks are expected to positively affect SF adoption and animal selection but impatience has a direct negative effect on farmers' adoption. Fifth, it is also speculated that patience increases with increasing wealth and religiosity.

The result from the bivariate model revealed that the expected yield positively influenced the adoption decision and full year application while yield variability and risk of yield failure had a negative effect on SF adoption decision and its full-year application. Besides, animal shocks are found to contribute positively to the adoption and application decision. In contrast to the prior expectation, impatient farmers tend to have a higher probability of practicing SF in full year. Little, if any, has been published on the explicit treatment of production risk, shock and discount rate on technology adoption. Thus, by explicitly considering production risk, shock and discount rate in the decision to adopt and apply SF, this paper adds to a very scarce literature in Ethiopia and all of sub-Saharan Africa. Measuring exogenous risk (production risk) from the milk production function further distinguishes this paper from previous studies, which explicitly focus on crop production.

The rest of the paper is organized as follows; the next section provides a brief survey of the literature. The third section outlines the theoretical model that guides the empirical work. There then follows (Section 4) with a full description of the survey data and experimental design. The empirical model is presented in Section 5 while Section 6 discusses the result. The last section concludes.

2. Literature Review

In most LDCs, rural farmers depend on mixed crop and livestock production, which is exposed to weather and human-induced risks (Tarawali et al., 2012). Rural farmers in Ethiopia face risks, including harvest failure caused by diseases, adverse weather, theft, predation, flood, fire, death (Roberts, 2007). Among the sources of risks, production risk related to livestock disease and mortality is perceived as the major sources of risk, which devastate households' livelihood and perpetuate the cycle of poverty by reducing livestock production and adoption of modern inputs (Bishu, 2014). Climate change disrupts the livelihoods of farmers (UNDP, 2013) by affecting the mean yield of the crops or milk but also inducing variability in yield. Besides, shortage of feed resources is a major cause of livestock production failure in Ethiopia.

Improving livestock productivity and ecological sustainability is suggested as the main pathway out of poverty in the region. Risk reduction strategy becomes then a higher priority agenda in the region by developing ways of reducing and coping with risk (e.g. crop diversification, selling livestock, improving the breed, stall feeding) in Ethiopia (Bishu, 2014; De Cao et al., 2013; Kahan, 2013). Farmers adopting SF protect their livestock from diseases and deaths due to cattle fighting, theft, predation, limited livestock contact and exposure to a high temperature by keeping cattle in their sheds (Bishu, 2014) and perceived production risks is lower compared to their counterparts.

Production risk or shock may be positively or negatively related to farmers' livestock feed technology. Risk-averse farmers may be sensitive to feed shortage and manage their livestock under SF well ahead of time as a relevant strategy to manage risk. On the other hand, less risk-averse farmers are keen for technology adoption such as stall feeding practices compared to risk-averse farmers (Bishu, 2014). Of particular interest has been the role of risk attitudes in technology adoption. As a result, much empirical evidence suggests that risk-averse individuals are less likely to adopt new technology, despite the risk-reducing nature of the technology (Liu and Huang, 2013). A farmer may choose to adopt feed-saving technology to hedge against weather risk (De Pinto et al., 2013).

The study conducted in Greece by Koundouri et al. (2006) indicated that production risk significantly affects irrigation technology adoption and farmers adopt the new technology in order to hedge against production risk. As of Tang et al. (2013), production risk was positively associated with the adoption of water-saving irrigation in China. Similarly, Juma et al. (2009) showed that yield variability and the risk of crop failure affect farm technology adoption in Kenya and higher expected yield was associated with high probability of fertilizer and improved maize adoption in Kenya (Ogada et al., 2014). Kassie et al. (2009) revealed that variance and crop failure had a negative significant impact on fertilizer adoption in Ethiopia, However, expected return positively affected fertilizer adoption and conservation adoption. Sauer and Zilberman (2009) indicated that the expected profit had a positive significant effect on the automatic milking adoption while profit variability and skewness of profit showed to have a significant negative influence on the adoption. In addition to the variance of return, downside risk (crop failure) may affect technology adoption (Di Falco and Chavas, 2009).

Regarding shock, relevant findings of Holden and Westberg (2016) indicated that the probability of using fertilizer was also negatively affected by rainfall risk in Ethiopia. Besides, farmers who face rainfall variability and rainfall shock were less likely to choose fertilizer over cash using a choice experiment. Likewise, Bezabih and Sarr (2012) found that covariate shocks from rainfall variability positively affect farmers' decision to diversify crops in Ethiopia. Ayenew et al. (2015) found that farmers with a higher level of relative risk premium were more likely to opt for crop diversification in Ethiopia. Gillespie et al. (2004) found that more risk-averse producers were more likely to adopt artificial insemination and breeding technologies. With regard to time preference, Duflo et al. (2011) argued that present-biased or impatient farmers postpone fertilizer adoption in Western Kenya inline to Le Cotty et al. (2014) whose result showed that impatience decreases grain storage adoption in Burkina Faso. Another related work is of Yesuf

(2004) whose result indicated that higher discount rate was correlated with low adoption of soil conservation technology in Ethiopia.

Despite the apparent importance of discounting behavior, there is little supporting evidence for its role in the technology adoption (Sunding & Zilberman, 2001; Chavas et al., 2010). The fact that these empirical studies focus mainly on crop than livestock technologies signals that there is a need for further research in the case of animal farming.

3. Theoretical Framework

In agricultural farming activity, uncertainty and risk are inherent features of agricultural production (Kumbhakar et al., 2006). Production uncertainty (production risk) make farmers' revenue uncertain where this is related to the uncertainty of the outcome due to weather conditions, and animal diseases, natural disasters, and even climatic changes in the long run. A theoretical framework that accounts for this production risk is specified following the model introduced by Antle (1987) and developed by Koundouri et al. (2006).

Since livestock farming in developing countries faces production uncertainty and market imperfection, the author uses an expected utility maximization framework to represent investment and production decisions made under uncertainty where the production risk is represented by a random variable, ε, whose distribution $G(.)$ is exogenous to the farmer's action. The farmer is assumed to be risk-averse and to produce a single output q but output prices, p, and input prices, r, are assumed to be non-random since farms in the sample are located in a relatively small geographic area where output and factor price variability is low. In addition, farmers have no price regulations (Koundouri et al., 2006). Farmers are further assumed to be price-takers both in the input and output markets. Stall feeding users assume that stall feeding (X_s) to be an essential input in cattle farming such as milk, meat and manure production process etc. Efficiency in feeding system is assumed to vary between farmers and is captured by incorporating parameter h(α) in the production function, where α is a vector of farmer's characteristics such as farm experience and education.

The production function is thus written as q = f [h(α) X_s X_{-s}], where X_{-s} represents the vector of all inputs except stall feeding. Assuming risk-averse farmers, the farmer's problem is to maximize the expected utility of gross income as defined below

$$\max_X E[U(\pi)] = \max_X \int [U(pf(\varepsilon, \mathrm{h}(\alpha) X_s\, X_{-s}) - rX)]dG(\varepsilon) \tag{1}$$

Where E is the expectation operator, π is the per-period return from farming, f is the well behaved (continuously and twice differentiable) production function, and U(.) is the Von Neuman-Morgenstern utility function. Given that p and r, are non- random, the first order condition (FOC) for stall feeding variable, X_s is rewritten as follows (dropping the subscripts for ease of notation):

$$\mathrm{E}(r_s * U') = E\left[p * \frac{df(\varepsilon, \mathrm{h}(\alpha)\, X_s\, X_{-s})}{dX_s} U'\right] \tag{2a}$$

$$\frac{r_s}{p} = E\left(\frac{df(\varepsilon, \mathrm{h}(\alpha)\, X_s\, X_{-s})}{dX_s}\right) + \frac{cov\left(U', df(\varepsilon, \mathrm{h}(\alpha)\, X_s\, X_{-s})/dX_s\right)}{\mathrm{E}(U')} \tag{2b}$$

Where U' represents the change in utility of income as a result of a change in income i.e., $U' = dU(\pi)\ /\ d\pi$. If cov$(.)$ =0, the left-hand side of $(2b)$ is equal to the first term on its right-hand side indicating that the expected marginal productivity of X_s, $df(\varepsilon, \mathrm{h}(\alpha)\ X_s\ X_{-s})/dX_s$ equals the ratio of input price over output price, r_s/p, In this case, the farmer is considered as risk-neutral and thus, adoption of improved technology is dependent on the traditional marginal conditions. For risk-averse farmers, the second term in the right-hand side of $(2b)$, $df(\varepsilon, \mathrm{h}(\alpha)\ X_s\ X_{-s})/dX_s/\mathrm{E}(U')$, is different from zero and would indicate deviations from the risk neutrality position. The term would be proportional and opposite in sign to the marginal risk premium with respect to the input under consideration, X_s, (Koundouri et al., 2006; Juma et al., 2009; Ogada et al., 2014). Therefore, adoption of improved technology would be influenced by production risk on the top of farm-specific factors that may influence either technology performance or adoption costs.

By incorporating the decision to adopt a stall feeding practice as a binary choice into the production model, the first order condition in the case of stall feeding adoption is modeled as:

$$\frac{r_s^1}{p} = E\left(\frac{df(\varepsilon, h^1(\alpha)\ X_s^1\ X_{-s}^1)}{dX_s}\right) + \frac{cov(U', df(\varepsilon, h^1(\alpha)\ X_s^1\ X_{-s}^1)/dX_s)}{\mathrm{E}(U')} \qquad (3a)$$

$$\frac{r_s^0}{p} = E\left(\frac{df(\varepsilon, h^0(\alpha)\ X_s^0\ X_{-s}^0)}{dX_s}\right) + \frac{cov(U', df(\varepsilon, h^0(\alpha)\ X_s^0\ X_{-s}^0)/dX_s)}{\mathrm{E}(U')} \qquad (3b)$$

Where X^1, X^0 denote the optimal input choices if the new technology is or is not adopted. Therefore, the farmer will adopt the new feeding practice if the expected utility with adoption, $\mathrm{E}[U(\pi^1)]$, exceeds the expected utility without adoption, $\mathrm{E}[U(\pi^1)]$, i.e.

$$\mathrm{E}[U(\pi^1)] - \mathrm{E}[U(\pi^0)] > 0 \qquad (4)$$

Risk-averse farmers who bear higher yield uncertainty is expected to have a higher probability of adoption as the new technology is more feed-saving and risk-reducing (Bishu, 2014). Information may have a positive value if by the assumption that future profit flows after adoption are uncertain and adoption of new feeding technology impose extra fixed costs (such as the construction of stable, feeding shelter and buying cart) (Dixit and Pindyck, 1984). Thus, farmers may prefer to delay adoption so as to get more information on the new technology. Thus, there may exist an additional cost entering the condition of adoption. The farmer will adopt now if:

$$\mathrm{E}[U(\pi^1)] - \mathrm{E}[U(\pi^0)] > \mathrm{V}, \qquad (5)$$

Where V ($\mathrm{V} \geq 0$) indicates the value of information for the farmer, which in its turn depend on the fixed cost of investment, the level of uncertainty related to the use of the new technology, and farmer's characteristics. In this paper, the role of information on the adoption decision is measured through the proxy variables of the education level of the farmer, social network, and information access via TV, radio and mobile (Koundouri et al., 2006).

4. Study area and Dataset

The study is conducted in the Tigrai region in the northern part of Ethiopia by randomly selecting 632 farm households. A mixed crop and livestock farming is the dominant livelihood system for smallholder farmers (Tesfay, 2010). Having a favorable environment for dairy production, the country is endowed with an estimated 12 million cows (Tegegne et al., 2013; CSA, 2016), which further indicates that 2.8 billion liters of milk were produced in 2012/2013, out of which 42.3% was used for household consumption. The dairy sector, however, is characterized by a large gap between its actual and potential contributions to the national economy and the welfare of rural people (Yilma et al., 2011). In the region, about 98.7% of the dairy cows are local breeds which partly resulting in low production and productivity of the sector. Based on national estimates, the average milk yield per cow per day for indigenous breeds is about 1.37 litres (Adane et al., 2015b) mainly constrained by the limited availability and low usage of improved dairy breeds, inputs and weak market linkages (Duncan et al., 2013) and low awareness of improved dairy management practices (Duguma et al., 2012).

Livestock feed resources in Ethiopia are mainly obtained from natural and improved pastures, crop residues, forage crops, agro-industrial by-products and nonconventional feeds (CSA, 2012). The contribution of these feed resources, however, depends upon the agro-ecology, the type of crop produced, and accessibility and production system. Most of the year, animals have to walk long distances in search of water and are usually watered once in two to three days. There is usually a gap of four to five months of the dry season before the start of the short rains. The gap which lasts for about 150 days between October and March is, therefore, the critical period in a feeding and watering system that is largely based on natural grazing pasture. Although the major feed resources are crop residues and natural pasture, their availability is gradually declining as a result of crop expansion, settlement and land degradation (Gebremedhin, 2009). According to CSA (2010c), the total agricultural land is reported to be about 16 million ha occupied by 12.9 million households accounting for an average of 1.23 ha per household, out of the total agricultural land, 75 % is used for temporary crops while grazing land accounts for 9%.

Based on Tesfaye (2010), the estimated crop residues from cultivated land contributes only about 45% of the animal feed demand in the region. It is stated that 73% of the animal feed is provided from natural grazing, 14% from crop residues, and the remaining 13% from other feed sources. The estimated crop residues from cultivated land in the region is found to be about 1,229,651 tons dry matter/year. The region has an estimated 878,322 ha of arable land available for crop production and contributes about 45% of the animal feed demand. Total grazing land in Tigrai is estimated to be 47,431 km^2 while tropical livestock unit (TLU) per km2 of grazing land was increased from 44,000 TLU in 2001/02 to 55,000 TLU in 2007/08. Thus, TLU per km^2 grazing land is in the region is above half for each year due to greater population density, larger herd sizes, and relatively fixed grazing land resources.

This study used cross-sectional data from Tigrai Rural Household Survey dataset collected in 2015 run by NMBU-MU[26]. Initially, to reflect systematic variation in agro-climatic conditions, agricultural potential, population density and market access conditions, four communities were selected from each of the four zones and three communities that represent irrigation projects. Likewise, one with low population density and one with high population density were strategically selected from each zone among communities to reflect far distance market (Hagos, 2003). The study was conducted in five zones covering 11 districts and 21 Tabias so as to yield 632 sample size. The dataset includes a panel of five rounds conducted in 1997/98, 2000/01, 2002/03, 2005/06

[26] Norwegian University of Life science –Mekelle University. This dataset has been initially used by Gehbru (2010); Holden et al. (2011) and Hagos (2003) for their PhD study.

and 2014/2015 where the author is involved only in collecting the data for the last round. A cross-sectional data set for the year 2014/2015 was extracted from the survey since some variables used in this paper were only added in the last wave. The estimation of production risk parameters further reduced the sample size to 367 farmers, including those who only harvested milk during the study year. The descriptive statistics of importance to the study are presented in Table1 and are discussed below.

Referring to Table1, the observable dependent variables, Y_1 in equations (3) takes a value of 1 if the farmer adopts SF practice, and 0 otherwise. The results indicated that 62% of a total of 367 livestock farmers were adopters of SF and 38% were non-adopters during the study period. The other dependent variable, Y_2 in equations (6) takes a value of 1 if the farmers choose to stall feed cows instead of other animals or to practice SF in a year-round than a single season, and 0 otherwise. Among 228 livestock farmers who were users of SF, 51% choose to feed cow under SF and, 63 % of them apply SF over a full year. Adopters of SF are seemingly worse off than non-adopters in terms of animal shock experience. Adopters on average experience more than twice as many as animal shocks as compared to non- adopters in the past four years. On the production risks, the average first moment, second and third moments are not statistically different between the two groups, but non-adopting farmers have slightly lower values compared with the value of adopters.

As reported in Table1, an average individual monthly discount factor, AVIDR[27], is 0.5. This discount factor is low, but consistent with previous research, which tends to find low discount factors in experimental studies (see Meier & Sprenger, 2010; Meier & Sprenger, 2013), whose result reveals an average individual monthly discount factor of 0.84 in Boston using the same experimental design and (Bauer et al., 2012) in which the average individual monthly discount factor is 0.6 in India using the same design. An average discount factor of 0.5 was found by Yesuf & Bluffstone (2008) in Ethiopia.

Access to credit by farmers facilitates labor hiring and thus promotes technology adoption. The findings indicated that adopters had the highest proportion of farmers that used credit (26%) followed by non-users (19%). Adopters of SF are seemingly worse off than non-adopters in animal shock experience. Adopters of SF seem to have a higher mean value (23%) in terms of animal shock exposure. Moreover, adopters have a significantly higher network (86%) as measured by gifts/assistance from relatives or friends as well as higher access to fodder shed (42%). The average farm size is 1.269 ha for users with a mean of 3.77 number of plots as compared to 1.125 ha for non-users. The result also indicated that the mean family size of adopting farmers is 6.3, with an average age of 55.8 years. On average, farmers who adopt SF spend 41.06 and 2016 minutes to travel to the nearest road service and to collect animal straw from threshing floor. SF users owned a herd size of 4.8TLU units with a mean of 1.76 milking cows while those non-users of SF owned about 5.8 TLU units with a mean of 1.8 milking cows.

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27) For a similar approach (see Ashraf et al., 2006; Meier & Sprenger, 2010; Bauer et al., 2012; Meier & Sprenger, 2013), and see the appendix for the full explanation of the field experiment.

Farmers using SF also spend 59 minutes than non-users who only spend 51 minutes per day to reach free grazing land. In relation to the village exposure to SF, on average SF users had 4 years' village exposure than non–users with 2.66 years, suggesting that farmers whose villages are exposed to SF had the necessary exposure to process information on this practice. Among male farmers, 77% are non-adopters and 72% are adopters. SF users had a significantly higher literacy level (69%) than that of non-users (25%). SF users own breed cows, on average 4 times higher than that of non-users. Moreover, 20% of the farmers reported to having access to information via radio, TV or mobile, of which 80% of them were found to be SF users. The proportion of SF adoption was highest for households living in the highland (67%) followed by 55% for non-users. Most of the highlands are attributed to low land holdings due to population pressure which forces farmers to invest in output -increasing or feed -saving practices.

4. 1. Measuring Time Preferences

In order to test whether heterogeneity in individual time preferences affects stall feeding adoption, we measure individual time preferences using a hypothetical question (Ashraf et al., 2006; Meier & Sprenger, 2010; Bauer et al., 2012; Meier and Sprenger, 2013) to link impatience measures to stall feeding adoption. In particular, I investigate whether individuals who exhibit present-biased preferences and impatience have higher or lower stall feeding adoption decision. Individuals under two multiple price lists were asked to make a series of choices between a smaller reward (X) in period t_0 and a larger reward (Y> X) in period t_1 keeping Y constant by varying X in two-time frames. In time frame 1, t_0 represents the present (t = 0) and t_1 is one month (τ =1); and in time frame 2, t_0 is six months from the study date (t_0 = 6) and t_1 is seven months from the study date (t_1 = 7) indicating that the delay length, d, is one month in both time frames. In both frames, the value of X varies from ETB 75 to ETB[28] 40 while Y is held constant to ETB 80.

Employing monetary rewards and multiple price lists as a preference elicitation mechanism enable us to identify differences in patience and present bias between individuals similar to time preference measures derived from other methodologies (Chabris et al., 2008). Time preference measures obtained from price lists at the individual level have been shown to be stable over time (see Meier and Sprenger, 2010). Using information from both price lists allows us to measure individual discount factors (IDF) and present and future bias. Individual discount factor (δ) is measured by taking the point in a given price list, X^* at which individuals switch from opting for the smaller (earlier payment) to opting for the larger (later payment). That is, a discount factor is taken from the last point at which an individual prefers the earlier smaller payment, assuming that $X^* \approx \delta^d \times Y$, where d represents the delay length (Meier & Sprenger, 2010; Bauer et al., 2012; Meier and Sprenger, 2013).

As the delay length, d, is always one month for both time frames, $\delta \approx (X/Y)^{\frac{1}{d}}$. Since our procedure produces two discount measures, $\delta_{0,1}$ and $\delta_{6,7}$, we use the average of these calculated

[28] ETB refers to Ethiopian currency where 1USD≈24 ETB during the study year,2015

monthly discount factors as the discount factor in the main analysis. Besides, we are able to measure present bias and future bias to identify dynamic inconsistency. An individual is present-biased if he is more impatient when presented with a choice with a shorter delay and more patient with longer delays and if the individual is future biased, more patient with a shorter delay and impatient with longer delays (Bauer et al., 2012). We classify an individual as present-biased if $\delta_{0,1}<\delta_{6,7}$, and as future-biased, if $\delta_{0,1}>\delta_{6,7}$. For our primary analysis, we use dummy variables present Bias (=1) and Future Bias (=1).

In order to validate our result cautiously, our elicitation design enables us to reduce the effect of seasonality on time preferences, as the future choice is shifted forward by exactly one month. In the long-term frame, we avoid proposing a choice between an amount now and a higher one a month from now. Instead, the choice is made between six months from now and seven months which involves front-end delay, in the sense that no reward is ever obtained without some minimal delay, allowing us to compare two uncertain choices and to avoid a possible bias toward the present and certain option as proposed by Frederick et al. (2002). The format used in this elicitation is presented in appendix A.

4. 2. Measuring Risk Preferences

Although our intention in this paper is not to estimate risk preference, we include risk preference in order to test the link between risk aversion and patience in our time preference estimation. Exploring people's risk preference through a field experiment in developing countries are mostly derived from the types of instruments developed by Binswanger (1980) or Holt and Laury (2002). While the Holt and Laury (2002) approach uses choices from a list of binary lotteries that differ in expected payoffs and variance to infer parameters for risk-aversion, the instrument we employed in this paper instead is similar to the approach of Noussair et al. (2013) and Drouvelis and Jamison (2012) in asking respondents to directly compare declining present choices with constant future choices.

A simple hypothetical risk elicitation instrument was presented to our respondents using a similar approach of Noussair et al. (2013) and Drouvelis and Jamison (2012) who measured risk aversion by counting the number of safe choices made by the individual in a five and seven list choices respectively. In order to elicit risk preferences, participants were shown a table with seven rows and asked to choose between a safe option and a lottery option in each row where the safe option is held constant in each row, but the amount in the lottery option increase from row to row. More precisely, in the first row subjects choose to receive 60 ETB with certainty, or they choose to play the lottery and have a 50% chance of receiving 0 ETB and a 50% chance of receiving 110 ETB. The amount in the lottery row increases from110 ETB to120, 130, 140, 160, 180, and 200 ETB. Our measure of individual risk aversion is the number of instances in which a respondent chose the certain row. Thus, our *risk aversion* measure ranges from a lowest possible value of 0 to the highest possible value of 7. Then respondents revealed their risk preferences by switching from option 1 to option 2.

A choice of zero safe option, out of seven choices indicates *risk preferring individual* and a *risk-neutral* individual would make either one or two safe choices, out of the seven choices, and more than two safe choices indicate *risk aversion*. More safe choices indicate greater risk aversion according to Noussair et al. (2013). Consulting the work of Drouvelis and Jamison (2012) as a measure of loss aversion, we used the frequency with which a subject chose the safe option. A detail elicitation table is presented in an Appendix B.

5. Analytical Method

5.1. Estimating Production Risk

Since the milk yield function is not necessarily affected by the adoption decision, moments of yield can be assumed exogenous to the adoption decision (see e.g. Antle and Goodger, 1984; Koundouri et al., 2006; Kassie et al., 2009; Kim and Chavas, 2003; Juma et al., 2009 and Ogada et al., 2014). The estimation procedure follows two steps: First, the first three sample moments (namely, mean, variance, and skewness) of each household were computed from the milk production function, then the estimated moments were included in the adoption decision discrete model. Adapting a sequential estimation procedure of Kim and Chavas (2003), milk yield was regressed on input variables to obtain estimates of mean. The general functional form of the model is:

$$\text{п}_i = f_1(X_i, \beta_1) + u_{i1} \quad (6)$$

Where i indicates individual farmers, п is milk yield per cow, X is the vector of variable inputs (labor, cow, feed and capital value), and $u_{i1}$is the usual error term with mean zero. The Ordinary Least Squares (OLS) results in consistent and efficient estimates of parameters $\beta_1$under the exogeneity assumption of the explanatory variables, (X) (Koundouri et al., 2006). The j^{th} central moment of the value of milk about its mean is, therefore, computed as:

$$\mu_j(X) = \text{E}\left[(\text{п}(X) - \mu_1)^j\right], \text{ for j = 1,. . . , m,} \quad (7)$$

Where μ_1 represents the mean milk yield or the first moment of yield. As a result, the estimated errors from the mean effect regression computed as $\left(e = \text{п} - f_1\left(X_i, \hat{\beta}_{i_1}\right)\right)$ are estimates of the first central moment of the yield distribution. Then, the estimated errors e are then squared and regressed in turn on the same set of explanatory variables so as to compute the second central moment of the milk yield following the model:

$$e_i^2 = f_2(X_i, \beta_2) + u_{i2} \quad (8)$$

The use of OLS on (8) gives consistent estimates of β_2 and the predicted values are consistent estimates of the second central moment of the yield distribution (the variance) adapting previous similar approaches (Antle, 1987; Kim and Chavas, 2003; Koundouri et al., 2006). Following the same procedure, the third central moment was estimated, by using the estimated errors (e) raised to the power of three, as the dependent variables in the same estimated models. Even if the distribution functions are well approximated by their first two moments, adding the third moment, which measures the probability of yield failure, might be vital for farmer's selection of production inputs (Antle and Goodger, 1984).

5.2. Econometric model of adoption

In the highlands of Ethiopia, mixed crop-livestock farming is the dominant form of smallholder agriculture throughout the regions. Farmers cannot keep as many animals as they wish to have. Feeding and watering animals is a significant cost of production where population pressure on natural resources is high and, resulting in low productivity (Devereux, 2014). Land degradation attributed to the heavy population pressure have caused declining and highly variable land and livestock productivity in Ethiopia, and Tigrai is well known for the devastating land degradation that has resulted in a decline in agricultural productivity (Kumasi et al., 2011). Due to this, the quantity and quality of free grazing lands in the highlands of Ethiopia, particularly Tigrai, is deteriorating from time to time. Therefore, individual farmers make a decision of adopting stall farming and feeding their all or selected animals annually or seasonally (Lenaerts, 2013; Bishu, 2014). Farmers also adopt stall feeding because free grazing exposes farmers' animals to wild animal attack, rampant disease, theft, flood, and is not proper for feed management and improving livestock income.

The analysis has two major steps. The first one is an estimation of production risk parameters using the three moments of milk yield distribution - the mean, variance, and skewness by selecting similar input variables used by Antle and Goodger (1984) and Just and Pope (1978). In the second stage, production risk parameter estimates were used to estimate the bivariate model for SF adoption decision and animal or seasonal selection. The decision to adopt SF practice and the decision to select which animal to feed under SF or which season to apply SF by farmers was considered to be a two-stage process. The first stage is whether farmers adopt SF or not while the second stage involved whether farmers choose feeding cows rather than another animal for SF, and practice SF in full-year rather than a single season after being users of SF. The second stage (outcome) stage is considered a sub-sample of the first stage (selection) stage. It is likely that the outcome stage sub-sample will be non-random and different from those farmers who did not adopt SF. A sample selection bias is then created (Heckman, 1979).

The first step is to create a model of farmers who are users of SF, and then given that model, the outcomes (choice) is modeled (Deressa et al., 2009). The author incorporates simultaneous decisions into the expected utility framework following Walton et al. (2008).

Let U_1^* be the farmer's expected utility from SF Adoption:

$$U_1^* = E[U_A] - E[\mathrm{U_N}] \tag{9}$$

Where U_A and U_N are the utilities from SF adoption and non-adoption. The latent variable, U_1^* is unobservable to researchers but assumed to be a function of exogenous variables so that

$$U_1^* = X'\beta + \varepsilon_1 \tag{10}$$

While X is a vector of exogenous variables, β is a vector of unknown parameters to be estimated assuming the error term ε_1 to have a normal distribution with zero mean. The decision of whether or not to adopt is observed by a discrete variable, Y_1

$$Y_1 = \begin{cases} 1 \; if U_1^* > 0 \\ 0 \; othewise \end{cases} \tag{11}$$

In the same fashion, let U_2^* represent the farmer's utility from feeding cow under SF or choosing the year round for SF practice:

$$U_2^* = (U_A | U_1^* > 0) - E[\mathrm{U_N} | \mathrm{U_1^*} > 0] \tag{12}$$

The first term on the right-hand side of equation (12) represents the actual realization of utility from adoption while the second term is the ex-ante expectation of utility from adoption. U_2^* is also unobservable variable, but assumed to be a function of observable variables such that

$$U_2^* = Z'\gamma + \varepsilon_2 \tag{13}$$

Where Z is of the vector of exogenous variables, γ is a vector of unknown parameters to be estimated, and ε_2 is the error term, also assumed to be normally distributed with zero means. The decision of whether to feed a cow or another animal under SF or to practice SF in full year or in a single season is also observed by a discrete variable, which we denote as Y_2

$$Y_2 = \begin{cases} 1 \ if U_2^* > 0 \\ 0 \ othewise \end{cases} \tag{14}$$

Substituting equation (10) into equation (11) and equation (13) into equation(14), the probability that the farmer chooses a cow to stall feed or chooses a year to practice SF is given by

$$Pr[Y_1 = 1, Y_2 = 1] = Pr[U_1^* > 0, U_2^* > 0]$$
$$= Pr[\varepsilon_1 > -X'\beta, \varepsilon_2 > -Z'\gamma]$$
$$= Pr[\varepsilon_1 < X'\beta, \varepsilon_2 < Z'\gamma]$$
$$Pr[Y_1 = 1, Y_2 = 1] = \Phi_2(X'\beta, Z'\gamma, \rho) \tag{15}$$

Where $\Phi_2$is the bivariate standard normal distribution and ρ is the correlation coefficient between the error terms ε_1 and ε_2. When ρ =0 equation (15) falls to a product of two univariate standard normal distributions of ε_1 and ε_2 or the two decisions farmers face are independent of each other. Since the probability of not choosing a cow or not practicing SF in a year-round is the difference of the probability of SF adoption and the probability of choosing a cow or practicing SF in a year-round, it can be obtained by subtracting the right hand side of equation (15)from the univariate probability distribution of SF adoption, defined as $\Phi(X'\beta)$.

$$Pr[Y_1 = 1, Y_2 = 0] = \Phi(X'\beta) - \Phi_2(X'\beta, Z'\gamma, \rho) \tag{16}$$

The probability of non-adoption can be then obtained by using equations (15) and (16) in order to fully explain the possible three states of this decision, cow/year selection, another animal/season selection and non-adoption of SF.

$$Pr[Y_1 = 0] = 1 - \Phi_2(X'\beta, Z'\gamma, \rho) - [\Phi(X'\beta) - \Phi_2(X'\beta, Z'\gamma, \rho)]$$
$$Pr[Y_1 = 0] = 1 - \Phi(X'\beta) \tag{17}$$

Having defined the three states, the objective of the econometric analysis is to maximize the likelihood function of each state which is given as follows:

$$L = \prod_{Y_1=1, Y_2=1} \Phi_2(X'\beta, Z'\gamma, \rho) \prod_{Y_1=1, Y_2=0} \Phi(X'\beta) - \Phi_2(X'\beta, Z'\gamma, \rho) \prod_{Y_1=0} 1 - \Phi(X'\beta) \tag{18}$$

Then the log-likelihood function is given as:

$$\ln L = \sum_{Y_1=1, Y_2=1} \Phi_2(X'\beta, Z'\gamma, \rho) + \sum_{Y_1=1, Y_2=0} \Phi(X'\beta) - \Phi_2(X'\beta, Z'\gamma, \rho) + \sum_{Y_1=0} 1 - \Phi(X'\beta) \tag{19}$$

I obtain maximum likelihood estimates by simultaneously equating the first derivatives of equation(19). Hence, my empirical model consists of two equations, one for adoption decision equivalent to equation (10) and the other for animal/season choice decision equivalent to equation (13) including the two vectors of exogenous variables, X, and Z, specified in equations (10) and(13), respectively.

Economic theory has traditionally taken time preferences as exogenous and given. However, the author has strong theoretical grounds to suspect that discount rate is endogenous due to measurement error and market imperfections. Time preferences are not readily observed, and empirical studies have to rely on proxies. Time preference may even depend on skills in imagining and valuing the future, making it endogenous rather than exogenous (Becker end Mulligan, 1997). Earlier evidence revealed that time preference is not a magic constant but is affected by a host of factors (Frederick et al., 2002). In that case, estimating Model (19) would result in biased estimates. Thus, a control function approach was employed to account for and test endogeneity bias in the case of a non-linear model when the suspected endogenous variable is continuous (Wooldridge, 2010).

As in a two-stage IV model, the control function approach requires an instrumental variable to be used in the first stage, reduced form estimation of the discount factor where the discount factor is instrumented by saving as a proxy for wealth and annual religious payment for religiosity. Becker & Mulligan (1997) have predicted that patience is positively related to wealth and religiosity but negatively related to death or illness. In the second stage, however, the structural equation was estimated with the observed endogenous variable and the residual obtained from the first stage as explanatory variables. The approach is merely to estimate a linear probability model using instrumental variable (IV), which is advocated by Angrist and Pischke (2009) when the outcome variable in the structural equation is binary so as to test the relevance and validity assumptions. On this approach, the Lagrange multiplier $\chi 2 -$ tests were used to test the relevance of instrumental variables. The test of endogeneity is the statistical significance of the coefficient of the residual (Wooldridge, 2010).

6. Estimation Results

6.1. Estimation of Discount Factor

Given that the discount factor is suspected for endogeneity in the models of adoption and choice, results from the reduced form estimations of discount factor using OLS, which are presented in Table 2 are discussed first. The result shows that the instrument variables are statistically significant and bear the expected signs. We used saving as a proxy for wealth and annual religious payment for religiosity. As predicted, the savers and religious people were found to be patient compared to their counterpart. Everything else remaining the same, both saving and religiosity increase patience by 8%, which is consistent with findings from (Becker & Mulligan, 1997; Nguyen, 2011; Liebenehm and Waibel, 2014). The Lagrange multiplier $\chi 2 -$ tests were used to test the relevance of instrumental variables and its χ^2 -value (19.5) confirmed that both instruments are relevant. Besides, the Sargan J –test fails to reject the null hypothesis that both instruments are uncorrelated with the error term in the structural model or all instruments are valid given its p-value of 0.202 at 5% level of significance. This helps me conclude that the instruments pass the over-identification requirement or exogeneity assumption.

In addition to the established link between wealth and discount factor, the literature shows that health outcome negatively affects time preference (Becker & Mulligan, 1997). My result confirms that family death shock significantly increases impatience by 0.09 units, which corresponds to the results of Sutter et al. (2013). Yet other variables have a significant effect on discount factors. Among the significant drivers of discount factor include the degree of risk tolerance and risk aversion. The results show that discount factor is negatively significantly affected by risk, implying that patience increases with the increase of risk tolerance, which is supported by evidence in Anderhub et al. (2001) and Anderson and Stafford (2009), who found that individuals become less patient as risk increases. Likewise, risk aversion decreases the discount factor in line to Abdellaoui et al. (2013) who report a negative correlation between risk aversion and impatience for gains. However, Farmers, with more years of literacy seem to be impatient as shown in their higher discount rate, which is inconsistent with findings from Vietnam (Tanaka et al., 2010).

The relationship between wealth and patience still holds true in our result, indicating that wealthier farmers, in terms of land and cattle, are found to be patient. This is consistent with findings in earlier studies (Tanaka et al., 2010; Nguyen, 2011; Liebenehm and Waibel, 2014). A positive relation was also found between access to credit and impatience. The further away the village is from the district market, the less patient the people are. This is in favor of Tanaka & Munro (2014). We also see that farmers from all zones have the highest average discount factors. As mentioned in the methods sections, residuals from the discount factor reduced form estimation are incorporated in the bivariate model to control for time preference endogeneity. The discount factor variable was found to be endogenous in these estimations, as the residuals from the first stage models were always found to be negative statistically significant in the case of the adoption decision model.

6.2. Bivariate Model

Estimation of the production function was useful only for generating production risks and its estimate results are presented in Table 4. Econometric results from the Univariate and Bivariate models were presented in Table 3. The results indicated that the model had good overall predictive power, as indicated by the overall 99% prediction for the selection model and 38% for the outcome model in the case of animal selection, and 15% in the case of seasonal selection. The Wald Chi-square test of independent equations examines the null hypothesis that the error terms in the two equations are uncorrelated. The correlation coefficient estimate of ρ= 0 and the p-value = 0.000 suggests that the two error terms are positively and statistically significant which justifies the use of bivariate probit model with sample selection, instead of two separate probits in the case of a seasonal choice model estimate. Exogenous variables included either in the adoption equation(10) or choice equation (13) had a significant predicting power of SF adoption and choice.

With respect to the farmers' production risk, the analysis revealed the following: As expected, production risks seem to have a central role in the decision to adopt SF and to choose which season to practice or animal to feed. The expected milk yield (first moment) had a positive significant effect on the adoption decision and season selection, indicating that the higher the expected return, the greater the probability of adopting SF in full-year than a single season. On the other hand, milk variability (second moment) and skewness of milk (third moment) showed to have a significant negative influence on the adoption and season selection probability. This implies that the higher the variance of return and probability of milk failure (downside risk) were, the lower the probability of adopting SF in the full-year term. Findings here are consistent with previous studies (Kassie et al., 2009; Sauer et al., 2009; Juma et al., 2009; Ogada et al., 2014).

In addition to production risk, individual shock exposure was also accounted for and captured by the frequency of animal shock exposure using survey measures. Animal shock is positively associated with adoption. This confirms the findings by Bezabih and Sarr (2012) who found that covariate shocks from rainfall variability were positively related to farmers' decision to diversify crops in Ethiopia. However, it contradicts with the results of Holden and Westberg (2016) in which the probability of using technology was negatively affected by rainfall variability and rainfall shock in the case of fertilizer in Tigrai region. Besides, Holden (2015) found that exposure to past drought shocks motivated poor farmers to adopt a drought tolerant maize but to dis-adopt local maiz*e* using mixed experiment and survey data in Malawi. In contrast to the hypothesis, a one-point increase in the farmer's average monthly discount rate increases the probability of adoption by 46%. This contradicts with the prior expectation and earlier findings (see Yesuf, 2004; Le Cotty et al., 2014; Duflo et al., 2011), but coincides with the reality that this technology is practiced more by poor farmers with a relatively less herd size and thus with a high discount factor due to the low cost of management. This implies that poor with a less herd size (impatient) are more motived to adopt SF due to easy SF management as compared to rich (patients), who have shown low desire to use SF.

Access to information positively and significantly affected adoption and cow selection confirming the result of Gunte (2015). Similarly, Deressa et al. (2009) discovered that information on climate change increased adoption of adaptation strategy. The proxy for social network showed to be positive and significant with respect to the SF adoption decision and season selection in line with the finding in Barret et al. (2001). There are empirical findings on the role of informal credit for the purchase of fertilizer (McIntosh et al., 2013). Gender had significant but a negative effect on adoption and full year SF application, in contrary to a study by Beshir (2014) in which male farmers were more responsive to forage adoption.

The level of education significantly and positively affected adoption and cow selection. Previous research (Feder et al., 1985; Gebremedhin & Swinton, 2003) indicated that farmers that have more years of schooling are more likely to realize the benefit of new technology and adopt it than their illiterate counterparts. As expected, age has a negative and significant effect on both adoption and selection models for the simple reason that younger people are more energetic for the farming activity. Results of this study support the principal hypotheses that adoption of SF and chance of choosing cow for SF is high in villages where SF is practiced, confirming the result of Sauer et al. (2009) in Europe and Beshir (2014) in Ethiopia. Labor positively influenced adoption and season selection. Similar signs are found for similar technologies (Beshir, 2014; Gebremedhin et al., 2003; Turinawe, 2012). Family size has a positive and significant relationship with the decision to adopt SF in full year, implying that people with higher family size show a greater interest in practicing SF the whole year.

While the ownership of improved cows, inline to Beshir (2014), promoted the chance of applying SF under the full-year term. Herd size was negative and significant determinants of adoption and selection. This is consistent with the findings of Kassie et al. (2009). Distance to nearest road was negatively correlated with joint adoption of SF and year selection, reinforcing the finding of Beshir (2014). Farmers with long distance to grazing lands site and crop residue site had a higher probability of adopting SF in full-year than their counterparts with a short distance. A 1% increase in the availability of land in hectare increased SF adoption by 4%. This result coincides with the finding of Beshir (2014).

7. Conclusion and Suggestions

Livestock farmers in developing countries experience risk and uncertainties. In Ethiopia, rural farmers are exposed to a variety of risks, including harvest failure, flood, frost, sickness, loss of stock, predation, input, and output price variability, the death and illness of livestock (Dercon, 2002). A number of feed management practices such as stall feeding (SF), rotational grazing, and tethering that could help mitigate the negative effects of these risks have been adopted. This paper seeks to answer the following research questions of i) Do farmers have a coping strategy that they opted for in order to curb the negative effects of production risks and shocks exposure? ii) May farmers view SF as risk-increasing or risk-reducing practice? iii) Are poor rural farmers impatient and less likely to adopt beneficial technology? iv) Are farmers in favor of full-year adoption of SF over a seasonal use and feeding cows under SF system over oxen?

In view of these research questions, the main objective of the paper was then to estimate the motivation for SF adoption and application using production risk, shock exposure and discount factor as key determinants of the joint decision. The study was based on a cross-sectional household survey data collected from a sample of 518 farmers during the 2015 farming season in Northern Ethiopia. A Control function based on bivariate probit approach was used to determine factors that affect SF adoption decision and choice of animal or season.

As expected, the discount rate variable was found to be endogenous, as the residuals from the first stage models were found to be negative and statistically significant. The empirical analysis revealed that production risk is a key determinant of SF adoption and full year application. The first moment has a highly significant positive effect on the adoption decision and full year SF application, implying that local farmers are driven by output maximization. Thus, they would be encouraged to use yield enhancing practices whenever it promises them higher returns. The second moment showed to have a significant negative influence on the adoption probability, and a higher probability of milk failure (downside risk) reduces the chance of SF adoption and full year application. This indicates that SF is only attractive and applicable to the local farmer when yields can be guaranteed. Thus, farmers seem to view SF as risk-increasing practice when the probability of milk production failure is high.

Results also show farmers shock exposure and time preferences to be important for the decision to adopt SF. In line with a priori expectations, shock exposure and higher discount rates, both significantly increased the probability of adopting SF. Interestingly, farmers with larger herd size showed less interest in adopting SF and feeding the cow. This coincides with the reality that SF is practiced more by poor farmers with relatively less herd size and thus with the high discount rate, indicating that impatient farmers were more likely to opt for full-year practice. However, the result contradicts with the previous notion that patient farmers adopt new technology.

Other factors having a significant positive effect on SF adoption and its application were: a social network, information access, family size and labor, distance to grazing land and crop residue, as well as the household's literacy and exposure to SF. Adoption of SF and feeding cow were supported by the younger, female households. Perhaps younger people are physically stronger to manage their livestock at home, and female farmers favored SF for feeding a cow than ox for the purpose of milk products.

How then can the results from this study be used to promoting the adoption of the new practices? The second and the third moments had a negative effect on SF adoption, indicating that farmers might view SF as risk-increasing practice. Policy-makers should then consider the importance of farmer's risk perception when promoting new technology adoption. Expected benefits that the farmer can derive from low production risk due to SF adoption should be included in the practice promotion agenda. Farmers' education and access to information appeared to play a significant role in adoption. Information diffusion using demonstration center appear to be justifiable to stimulate and nurture the adoption process. A better coordination by extension agents seems to be needed to facilitate the intensification of SF and the dissemination of consistent information regarding its benefit. The implication is that intervention that reduces the variance of return and exposure to downside risk are some desirable in the adoption and choice decision.

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Table1. Description and Summary Statistics for SF Adoption Decision

VARIABLES	Description	Non-adopters mean	Adopters mean	T=test P-value (5%)
Network(1= if household got assistance from relatives & friends)		0.237	0.855	0.0000
Gender (1= Male)		0.770	0.728	0.3759
Education (1= Literate)		0.252	0.688	0.0000
Credit (1= Access to credit)		0.194	0.263	0.1328
Animal shock (1=animal shock from 2012 to 2014)		0.158	0.232	0.0878
Improved (1=breed cows)		0.0144	0.061	0.0324
Information (1=own Radio, TV and Mobile)		0.374	0.800	0.0000
Location (1= if household lives above 2000m.a.s.l		0.554	0.666	0.0306
Distance to nearest road (walking minute)		50.00	41.06	0.0363
Household age (years)		57.19	55.83	0.4196
Total livestock (TLU)		5.082	4.810	0.4302
Total cows (number)		1.835	1.768	0.6716
Total labor time spent for cattle feeding(hour)		43.72	334.0	0.0000
distance to free grazing (walking minute)		51.80	59.06	0.1355
Feed transporting time (walking minute)		729.3	2,016	0.3165
Average monthly discount factor		0.464	0.409	0.1660
Total plots (number)		3.432	3.772	0.1133
Farm size owned (hectare)		1.125	1.269	0.1420
Total own produce feed value		5415.2	6367.8	0.0706
Village Experience of SF(year)		2.662	4.013	0.0000
Total daily milk harvest (Littre/per cow /day)		1.156	1.321	0.2720
Value of farm tools(cart, water tanker, cattle &fodder shed) (ETB)		789.4	847.9	0.7469
First moment(expected mean)		0.230	0.168	0.2632
Second moment (variance of yield)		0.438	0.441	0.7069
Third moment (Skewness of yield)		-0.0102	-0.046	0.1575
Total family size (number)		5.813	6.364	0.0255
Sample size		139	228	
Dependent variables in the first & second equations				
SF adoption	1 if household adopt SF	0.380	0.620	
Animal choice	1 if household feed only cows under SF		0.513	
	2 if household feeds only an ox under S		0.487	
Seasonal choice	1 if household practices SF the whole year		0.632	
	0 if household practices SF in a single season		0.368	

Source: Own compilation, 2016

Table 2 OLS Estimation of Average Individual Discount Factor

VARIABLES	(OLS) Average discount rate
Saving in forma financial institution(Yes=1)	-0.0850***
	(0.0324)
Health shock exposure of the household head during the survey(Yes=1)	0.0889*
	(0.0471)
Annual religious payment by household to a father priest(Yes=1)	-0.0787***
	(0.0304)
Location of household heal(highland=1)	-0.00565
	(0.0527)
Tolerance (willingness to invest in a 5 year benefit from now; if yes=1)	-0.0549*
	(0.0305)
Average rainfall of 2003-2014 (mm)	0.0045*
	(0.0023)
Household age (years)	-0.0009
	(0.0010)
Gender(1=Male)	0.0018
	(0.0314)
Education of household head (1=Literate)	0.0518*
	(0.0290)
Distance to market (minute)	0.0006**
	(0.0003)
Total family size(number)	0.0077
	(0.0061)
Total owned oxen (number)	-0.0178*
	(0.0101)
Total farm size owned (hectare)	-0.0230*
	(0.0126)
Access to farm tools: cart, cattle &fodder shed *(Yes=1)*	0.0753**
	(0.0302)
Risk preference[a]	-0.0112*
	(0.0066)
Access to formal credit(Yes=1)	0.0555*
	(0.0323)
South East(Yes=1)	0.132*
	(0.0735)
Eastern(Yes=1)	0.156*
	(0.0796)
Central(Yes=1)	0.166**
	(0.0693)
Southern(Yes=1)	0.185***
	(0.0681)
Constant	0.343*
	(0.200)
Observations	518
R-squared	0.118

NB: ***, **, *Implies that the estimated parameters are significantly different from zero at 1, 5, and 10% significance level, respectively. Figures in parentheses are standard errors; [a] please refer to Appendix B for its measurement

Table 3 Univariate and Bivariate Estimation of SF Adoption and Animal or Seasonal Choice

VARIABLES	(Univariate) Adoption	(bivariate: Animal Choice) Adoption	cow	(bivariate: Seasonal Choice) Adoption	year
expected mean (First Moment)	0.107***	0.108***	0.0477	0.106***	0.135**
	(0.0397)	(0.0396)	(0.0891)	(0.0374)	(0.0657)
variance of yield (Second moment)	-0.434**	-0.438**	-0.0890	-0.388**	-0.230
	(0.200)	(0.199)	(0.371)	(0.190)	(0.275)
skewness of yield (Third moment)	-0.157*	-0.155*	0.0707	-0.154*	-0.464***
	(0.0904)	(0.0903)	(0.218)	(0.0815)	(0.168)
Family size (number)	-0.0018	-0.0016	-0.0157	-0.0020	0.0147*
	(0.0055)	(0.0054)	(0.0117)	(0.0052)	(0.0083)
Network (1/0)	0.0676***	0.0677***	0.0211	0.0721***	0.296***
	(0.0261)	(0.0258)	(0.0700)	(0.0249)	(0.0526)
Animal shock of 2012-14 (Yes=1)	0.0548***	0.0553***	-0.0308	0.0533***	-0.00981
	(0.0185)	(0.0183)	(0.0334)	(0.0178)	(0.0230)
Average discount rate(scalar)[a]	0.454***	0.450***	0.381	0.477***	0.201
	(0.141)	(0.140)	(0.282)	(0.146)	(0.194)
Information(TV, radio & mobile =1)	0.0736***	0.0739***	0.0827	0.0672***	-0.0151
	(0.0251)	(0.0250)	(0.0643)	(0.0233)	(0.0447)
Improved (Bred cow=1)	-0.0527	-0.0530	0.123	-0.0442	0.173*
	(0.162)	(0.149)	(0.120)	(0.150)	(0.0955)
Village Exposure of SF (years)	0.0225***	0.0221***	0.0188***	0.0257***	0.0013
	(0.00736)	(0.0073)	(0.0072)	(0.0078)	(0.0043)
Labor (hour)	0.0003***	0.0003***	0.0001	0.0003***	0.0004***
	(7.86e-05)	(7.77e-05)	(0.0001)	(7.42e-05)	(8.44e-05)
Age of household head (years)	-0.0018**	-0.0018**	-0.0042***	-0.0018**	0.0011
	(0.0008)	(0.0008)	(0.0016)	(0.0008)	(0.0011)
Gender of head (Male=1)	-0.0558**	-0.0530*	-0.0815	-0.0526*	-0.0676*
	(0.0275)	(0.0281)	(0.0558)	(0.0269)	(0.0366)
Education of head (literate=1)	0.0412*	0.0423*	0.104**	0.0441**	-0.0273
	(0.0241)	(0.0240)	(0.0520)	(0.0225)	(0.0366)
Herd size (TLU)	-0.0098**	-0.0101**	-0.0265**	-0.0099**	0.0018
	(0.0047)	(0.0047)	(0.0105)	(0.0049)	(0.0067)
Feed transporting time (minutes))	9.59e-06**	9.70e-06**	-1.45e-05	9.36e-06**	-0.0001**
	(4.30e-06)	(4.29e-06)	(2.93e-05)	(4.14e-06)	(5.21e-05)
Distance to free grazing (minutes)	0.0013***	0.0013***	-5.86e-05	0.0012***	0.0016***
	(0.0002)	(0.0002)	(0.0004)	(0.0002)	(0.0001)
Distance to road (minute)	-0.0007**	-0.0007**	0.0006	-0.0007**	-0.0017***
	(0.0004)	(0.0004)	(0.0006)	(0.0004)	(0.0005)
Farm size owned (hectare)	0.0413*	0.0400*	-0.00244	0.0385	-0.0076
	(0.0228)	(0.0228)	(0.0205)	(0.0234)	(0.0161)
Location (highland=1)	-0.0212	-0.0227	0.0755	-0.0823**	0.0084
	(0.0542)	(0.0532)	(0.0947)	(0.0397)	(0.0622)
Predicted error from reduced form	-0.254*	-0.251*	-0.452	-0.280**	-0.0909
	(0.130)	(0.129)	(0.277)	(0.133)	(0.180)
Predicted prob	0.991	0.991	0.377	.996	0.149
Wald Statistics ,$H_0 : \rho(Rho)$=0		Pr-value (5%)= 0.6501		Pr-value (5%)= 0.003	
Observations	367	367	288	367	288

NB: Asterisks (***, **, *) imply that the estimated parameters are significantly different from zero at 1, 5, and 10% significance level, respectively. Figures in parentheses are standard errors

[a] I use saving and annual religious payment of household as instrument for the discount rate estimation in this study

Table 4 Estimated Cobb-Douglas of Milk Production Function, 2015

INPUT VARIABLES	(OLS) lnmilkyield
lncow(number of milking cows)	0.188***
	(0.0652)
lnTLT(total labor time spent on cattle)	0.0292
	(0.0399)
lnfvalue (total farm tool value)	0.114***
	(0.0241)
Lnpfvalue (total own produce feed value)	0.286***
	(0.0342)
Constant	-3.074***
	(0.354)
Observations	367
R-squared	0.363

NB: Asterisks (***, **, *) imply that the estimated parameters are significantly different from zero at 1, 5, and 10% significance level, respectively. Figures in parentheses are standard errors

Appendix A. Choice Experiment for Time Preference

Individual discount factor (δ) is measured by taking the point in a given price list, X^* at which individuals switch from opting for the smaller (earlier payment) to opting for the larger (later payment) using a hypothetical questions[29]. That is, a discount factor is taken from the last point at which an individual prefers the earlier smaller payment, assuming that $X^* \approx \delta^d \times Y$, where d represents the delay length. As the delay length, d, is always one month for both time frames, $\delta \approx (X/Y)^{\frac{1}{d}}$ .Since this procedure produce two discount measures,$\delta_{0,1}$ and $\delta_{6,7}$, the average monthly discount factors is used as the discount factor in the main analysis. The author classify an individual as present-biased if $\delta_{0,1} < \delta_{6,7}$, and as future-biased if $\delta_{0,1} > \delta_{6,7}$ to use in the analysis.

Instruction: Please indicate for each of the following 12 decisions, whether you would prefer the smaller payment in the near future (A) or the bigger payment later (B). Switching from option A to option B is possible at any point.

S/N	**Option A: Today (t_0 = 0)**	**Decision: A or B**	**Option B: 1 Month (t_1 = 1)**
1	ETB 75 guaranteed today		ETB 80 guaranteed in a month
2	ETB 70 guaranteed today		ETB 80 guaranteed in a month
3	ETB 65 guaranteed today		ETB 80 guaranteed in a month
4	ETB 60 guaranteed today		ETB 80 guaranteed in a month
5	ETB 50 guaranteed today		ETB 80 guaranteed in a month
6	ETB 40 guaranteed today		ETB 80 guaranteed in a month
	Option A: six month (t_0 =6)		**Option B: 7 Month (t_1 = 7)**
7	ETB 75 guaranteed in 6 month		ETB 80 guaranteed in 7 month
8	ETB 70 guaranteed in 6 month		ETB 80 guaranteed in 7 month
9	ETB 65 guaranteed in 6 month		ETB 80 guaranteed in 7 month
10	ETB 60 guaranteed in 6 month		ETB 80 guaranteed in 7 month
11	ETB 50 guaranteed in 6 month		ETB 80 guaranteed in 7 month
12	ETB 40 guaranteed in 6 month		ETB 80 guaranteed in 7 month

Appendix B. Hypothetical Risk

A simple hypothetical risk elicitation instrument was presented to the respondents[30] to measure risk aversion by counting the number of safe choices made by the individual in a five and seven list choices respectively. A choice of zero safe option, out of seven choices indicates risk preferring individual and a risk neutral individual would make either one or two safe choices, out of the seven choices, and more than two safe choices indicate risk aversion.

Instruction: choose either option A, which gives you a certain 60 ETB or option B with 50% chance of getting 0 and 50% chance of getting the specified ETB amount. You can switch from option A to option B at any point you want to switch.

Risk				
Option A		A or B	Option B	
1	100 % of 60 ETB		50 % 0 and 50% 110 ETB	
2	100 % of 60 ETB		50 % 0 and 50% 120	
3	100 % of 60 ETB		50 % 0 and 50% 130	
4	100 % of 60 ETB		50 % 0 and 50% 140	
5	100 % of 60 ETB		50 % 0 and 50% 160	
6	100 % of 60 ETB		50 % 0 and 50% 180	
7	100 % of 60 ETB		50 % 0 and 50% 200	

[29] See for more details (Ashraf et al. 2006; Bauer et al. 2012)

[30] See for similar approach (Noussair et al. 2012; Drouvelis et al. 2012; Meier and Sprenger 2013)

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The dissertation used a cross-sectional data from NMBU-MU Tigrai Rural Household Survey collected in 2015 on a randomly selected 632 sample households. The main dissertation is composed of 4 manuscripts. The first paper attempts to examine the effect of rising population pressure on (I) farm and herd size (ii) modern input use and farm output using recursive structural equation methods with 518 sample size. The finding reveals that both Malthusian and Boserupian forces co-exist. Population pressure affected both input demand and output supply.

In the second Paper, we pay specific attention to the economic effect of resource (grazing, water and crop residue) scarcity on labor for crop farming and crop food production. Our results favor the hypothesis of a negative relationship between labor input to crop farming and resource scarcity. In aggregate, the findings confirm that reducing time spent looking for water and animal feed increases food production.

Paper 3 focus on the link between animal resource scarcity and welfare and food security. In aggregate, our principal findings confirmed that resource scarcity affect household welfare and food security adversely while Paper 4 assess the link between production risk and Time preference and animal feeding practice and feeding choice. Our empirical analysis revealed that production risk and time preferences are key determinant of SF adoption and full year application.

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