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Innovation Capacity in Dairy Production Systems:
A Study in the Northwest of Ethiopia

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"The fear of the LORD is the beginning of wisdom, and knowledge of the Holy One is understanding"

Proverbs 9:10

DEDICATION

I dedicate this work to my loved wife Genet Kifle and our children Yeabtsega, Bereket, Rediet and Mercy. You were the source of my strength, joy and inspiration; and my mother for her love and dedication. I was really missing you very much.

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SUMMARY

Agriculture is central to Ethiopian economy but its sustainable development faces enormous challenges. Low innovation capacity, low productivity, dwindling natural resources and climate change, small-scale subsistence farming, and low levels of market integration and value addition have all made agricultural development more complex. In spite of the decades of research and development efforts, the rate of growth for both crop and livestock productivity has remained low. This study seeks to understand how the innovation system in the dairy sector is working to better support farmers with strong networks and therefore to contribute towards enhancing productivity, increasing food security and nutrition, diversifying rural livelihoods and reducing poverty.

The study examines (1) the innovation systems and networks that influence (impair or support) change in dairy production systems; (2) the impact of social networks on smallholder dairy production technology adoption; and (3) the extent and determinants of smallholder household's production efficiency in the context of local level agricultural innovation systems framework.

Primary data were collected during 2010 and 2011 production year from a sample of 304 smallholder farm households in four selected districts. Social network analysis method is used to investigate the innovation landscape at the local level. Combined social network analysis and economic approaches is used to analyze dairy production adoption that incorporates social learning. Cobb-Douglas stochastic frontier production function was modeled to estimate the level of technical efficiency and its determinants.

The innovation systems and networks study suggests that public sector actors are the major role players in the dairy production system despite their minor role in marketing linkages. The study also shows that the private sector actors play peripheral roles in the network. Differences between innovator and non-innovator social networks were observed, with innovators exhibiting greater access to sources of production knowledge, inputs, credits and markets. Some important organizations that could strengthen the stakeholders' ability to identify, implement and adapt sustainable practices are missed in the process.

Social networks impact study reveal that smallholders acquire knowledge about improved dairy practices mainly from the public extension system (extension network), and to a lesser extent through their close associates (peer networks). On the other hand the study shows that the potential contributions of community and market networks that can significantly affect adoption remain untapped.

The technical efficiency study shows that the mean level of technical efficiency among the sampled farmers was about 26 percent. This finding shows that there is room for significant increase of production by reallocation of the existing resources. Despite significant variation among farmers, these results also indicate only 19% of farmers have mean efficiency scores ($\geq$50%), implying a need to focus on creating innovation capacity that pushes the production frontier outward in the dairy production system. It is also revealed that individual farm households' efficiency varied widely across dairy technology adoption status, gender and districts. The study also shows significant variation in the output of milk production would be attributed to technical inefficiency effects (those under farmer's control) and hence calling for a focus on efficiency enhancing investments. Education, farm size, extension visit and off-farm income opportunity were found to be efficiency enhancing.

In sum, further development of the dairy innovation systems at the local level is critical to the creation of a more commercialized dairy sector where dynamic and responsive networks are effective in responding to dairy production and productivity at household, regional and national level.

It is recommended for policies and programs: (1) To reform the current agricultural extension system to address institutional and policy issues that constrain effective agricultural innovation system; (2) Given the adoption of dairy production technologies as an essential means of boosting productivity, there is an immediate need to focus on the innovative use of all kinds of social networks, and therefore to design suitable strategies that leverage social networks to complement the current extension approaches. (3) Different components of an agricultural innovation system have to interact to improve the innovation capacity of different actors and there by improve the estimated technical inefficiencies.

ZUSAMMENFASSUNG

Die Innovationskapazität im Milchsektor: Eine Fallstudie im Nordwesten von Äthiopien

Die Landwirtschaft spielt in Äthiopien eine zentrale Rolle, ist jedoch mit enormen Herausforderungen hinsichtlich nachhaltiger Entwicklung konfrontiert. Unterschiedliche Faktoren wie geringe Innovationskapazität, niedrige Produktitvität, schwindende natürliche Resourcen, Klimawandel, schwache Marktanbindung von Kleinbauern sowie eine schlecht ausgebildete Wertschöpfungskette erhöhen die Komplexität und erschweren die Entwicklung des Agrarsektors. Trotz jahrzehntelanger Forschungs- und Entwicklungsaktivitäten bleibt die Produktivität von Ackerbau und Tierhaltung nach wie vor auf niedrigem Niveau.

Im Rahmen dieser Studie soll erarbeitet werden, wie das Innovationssystem im äthiopischen Milchsektor funkioniert um Bauern und Bäuerinnen in starken Netzwerken zu unterstützen und dadurch zu Produktivitätssteigerung, Ernährungssicherheit, Diversifikation landwirtschaftlicher Einkommensquellen und Armutsreduktion beiträgt.

Die Studie betrachtet (1) Innovationsysteme und Netzwerke die Veränderungen im Milchsektor unterstützen oder erschweren; (2) den Einfluss sozialer Netzwerke auf die Einführung von Technologien der Milchproduktion durch Bauern und Bäuerinnen; (3) Ausmass und Merkmale von Produktionseffizienz kleinbäuerlicher Betriebe im Kontext lokaler, agrarischer Innovationssysteme.

Daten von 304 kleinbäuerlichen Betrieben aus vier Provinzen im Nordwesten Äthiopiens wurden 2010/11 erhoben. Soziale Netzwerkanalyse wurde, zur Darstellung der Innovationslandschaft auf lokaler Ebene, angewendet. Eine Kombination sozialer Netzwerkanalyse und öknomischer Zugänge wurde verwendet, um die Einführung von Technologien in der Milchproduktion, inklusive sozialer Lernenporzesse, zu erfassen. Mit Hilfe der stochastischen Cobb-Douglas Grenzfunktion wurden Niveau und Merkmale der technischen Effizienz erhoben.

Die Ergebnisse zeigen, dass öffentliche Akteure eine dominante Rolle in der Milchwirtschaft innehaben, obwohl ihnen nur eine untergeordnete Bedeutung in der Vermarktung zukommt. Private Organisationen spielen eine periphere Rolle in Milchproduktionsnetzwerken. Es konnten Unterschiede zwischen Innovatoren und Noninnovatoren beobachtet werden.

Innovatoren haben besseren Zugang zu produktionsspezifischem Wissen, Krediten, Märkten und Produktionsmitteln. Institutionen, die zur Stärkung der Fähigkeiten von Akteuren in den Bereichen Identifikation, Anwendung und Anpassung nachhaltiger Produktionsmethoden beitragen könnten, fehlen in den Produktionsnetzwerken.

Die soziale Netzwerkanalyse konnte zeigen, dass Bauern und Bäuerinnen ihr Wissen über verbesserte Produktionsmethoden in der Milchwirtschaft hauptsächlich von Vertretern des staatlichen landwirtschaftlichen Beratungssystems beziehen und nur zu einem geringen Ausmass auf das Wissen anderer Bauern zurückgreifen. Dies zeigt, dass das Potenzial von gemeinschaftlichen Netzwerken und Netzwerken zur Erschließung von Märkten nicht voll ausgeschöpft wird.

Die Messung der technischen Effizienz zeigte, dass Betriebe im Durchschnitt Effizienzwerte von 26% erreichen. Ein Hinweis darauf, dass signifikanter Spielraum zur Produktionssteigerung, über eine Umverteilung bestehender Resourcen, vorhanden ist. Die Ergebnisse weisen eine sehr hohe Streuung zwischen individuellen Betrieben auf und nur 19% der Betriebe erreichen einen Effizienzwert von oder höher als 50%. Dies weist auf die Notwendigkeit hin, einen Schwerpunkt auf die Schaffung von Innovationskapazität zu legen, um die Produktivität der Milchproduktionssysteme zu verbessern. Die Effizienz der Einzelbetriebe variierte stark zwischen Betrieben mit unterschiedlichem Technologiestatus, mit Betriebsführern unterschiedlichen Geschlechts sowie auf verschiedenen Standorten. Die signifikante Streuung der Erträge aus der Milchproduktion können auf technische Ineffizienz zurückgeführt werden, die von Bauern und Bäuerinnen kontrolliert werden kann.

Folgende Schlussfolgerungen können aus dieser Studie abgeleitet werden: (1) Politiker und Programmverantwortliche sollten eine Reform des bestehenden Beratungssystems anstreben, um institutionelle und politische Probleme zu beheben, die momentan die Effektivität landwirtschaftlicher Innovationssysteme einschränken. (2) Einführung von landwirtschaftlicher Technologien sollte als wichitges Mittel zur Steigerung von Produktion, Produktivität und bäuerlicher Einkommen anerkannt werden. Verfechter solcher Technologien müssen ihre Strategien überdenken und sich auf die innovative Nütung sozialer Netzwerke konzentrieren, um die Verbreitung von Technologien zu fördern und ihre Einführung durch Bauern und Bäuerinnen zu beschleunigen. (3) Die einzelnen Komponenten des Innovationssystems müssen zusammenspielen, um die Innovationskapazität und technische Ineffizienz zu verbessern.

CHAPTER 1. INTRODUCTION

1.1. Background

Developing-country agriculture is frequently characterized by low innovation capacity (Juma 2011), low productivity (UNDP 2012; World Bank 2008), demographic pressure, dwindling natural resources and climate change (Jayne et al., 2010), small-scale subsistence farming, and low levels of market integration and value addition (World Bank, 2008). However, there is significant variation across developing countries (UNDP, 2012). This suggests a need for a better understanding of the factors that influence productivity and variations in productivity among countries, development sectors and farm enterprises.

Ethiopia is one of the most populous countries in the developing world and agriculture is central in its economy. The agriculture sector is a major source of livelihood for 80% of the population in the country (MoFED, 2010). The livestock sector in particular is an indispensable component to sustain the agricultural system, accounts for about 45% of the agricultural GDP (IGAD, 2010) and directly supports the livelihoods of 60-70% of the population (Anteneh, 2008). The dairy sector in Ethiopia holds large potential to contribute to the commercialization of the agriculture sector and food security due to the country's large human and livestock population, suitable agro-ecologies, culture of milk consumption, etc (Azage et al., 2012). Ethiopia has about 50 million cattle and about 10 million are cows (CSA, 2010) and the dairy sector contributes to half of the livestock output (Tesfaye *et al*., 2008).

Nonetheless, there is a great concern that productivity of livestock, especially the dairy sector, in Ethiopia is still very low compared to other neighboring countries. For example, milk productivity is among the lowest in East Africa. It is estimated to be 270 litres per cow per lactation versus 498 and 480 litres in neighbouring countries like Kenya and Sudan, respectively (Tesfaye et al., 2010). A wide gap exists between actual dairy farm production and potential productivity identified in research stations (EARO, 2006), pointing to low innovation capacity, slow rate of technology adoption and potential technical inefficiency in the current dairy production practices.

Similarly, several studies have argued that Ethiopia's innovation system is inadequate relative to the development challenges facing the country. According to the Knowledge Assessment

Methodology (KAM) Knowledge Index (KI) which measures the country's ability to generate, disseminate and use knowledge, Ethiopia ranks 140th among the 145 countries assessed (KAM 2012). As a result the country is suffering from low productivity of the agricultural sector and particularly that of the livestock sub-sector.

In spite of the decades of research and development efforts, the rate of agricultural technologies adoption[1] has remained low. For example, between the years 1974 to 2004, cereal and livestock technologies released were 83 and 14, respectively, of which those directly related to production are 44 (53%) and 6 (43%), respectively (EARO 2006). Nationally, only 18 % of farmers enrolled in extension programs have participated in livestock packages, although there is a big debate about the whole package[2] approach (MoARD 2010); crossbred and exotic dairy cattle constitute less than two percent of the total population of milking cows in the country (CSA 2012a). Due to the slow innovation and technology transfer in the livestock sub-sector, the country's milk productivity level per cow per year stagnated for decades during 2001 to 2011 (CSA 2012a).

In addition, there are considerable inefficiency challenges that have greatly retarded the productivity of the livestock sector in Ethiopia: (1) livestock agriculture lacked the policy level attention it deserves (Gelan et al., 2012). For example, the Ethiopian public agricultural research staff allocated to crop research accounts for 56.8 % whereas only 14.2 % researchers focused on livestock (IFPRI, 2011); (2) slow innovation and technology transfer is observed, such as shortage of genetic material, insufficient supply of forage crop seeds and feed concentrates; complementary services such as extension, credit, breeding, veterinary service, and input-output marketing are poor (MoARD, 2010); and (3) although Ethiopia has one of the largest public-supported agricultural extension services in the world next to China, for example the number of extension workers per 10,000 farmers is thirteen as compared to sixteen, six, four, three and two for China, Indonesia, Tanzania, Nigeria and India, respectively (Davis et al. 2009), the public extension service role is criticized as confined to a linear model of technology transfer and was limited in its relationship with the wide range of knowledge sources (World Bank, 2010). Thus, it could not bring the breakthrough needed to transform the agricultural sector. All these constraints need to be considered to evaluate where further efficiency gains are possible.

[1] The term "adoption" refers to the individual behavior towards an innovation.
[2] Full package denotes the targeting, selection of technology, the delivery mechanism (extension), the input supply and the credit schemes, and its attempt to link farmers to markets.

A number of studies have examined the potential of the Ethiopian dairy sector to meet the expected growth in demand as well as to improve the incomes of the farmers (Benin, et al., 2002; Feleke, 2003; Ahmed, et al., 2004). Many of those studies, however, focus on technological constraints of the sector including poor genotype of local breed animals, animal diseases, availability of feed, input and output markets, and related policies. The studies ignore an important source of growth – the capacity of the innovation system actors to generate, exchange, and use of dairy-related knowledge in process of production. Literature tells that a well facilitated innovation system: (1) enhances technology transfer; (2) ensures demand driven technological development; (3) enhances adoption and impact; and (4) builds up technical competence and thereby efficiency (Anandajayasekeram et al. 2009).

Recent research has highlighted innovation systems perspective as a study framework (Hall *et al.* 2008; World Bank 2006a; Clark 2002) to explore the capacity for innovation in several key areas of technology, organization and institutions. However, in Ethiopia, this literature has yet to be juxtaposed in a detail manner with empirical evidence and little is known about how technological, organizational and institutional innovation[3] collectively enhances smallholder productivity. To date, no study has been conducted in relation to local innovation networks in the Ethiopian livestock sector. Furthermore, little use of the technique has been made so far for social network analysis in developing country agriculture in general and Ethiopia in particular (Spielman *et al.* 2010).

Hence, this study explores new inroads for the understanding of rural innovation processes in the dairy sector, emphasizing, in particular, how innovation systems and networks influences smallholder innovation processes; how social networks contribute to the efforts to increase productivity through adoption of dairy technologies; and how different components of the local-level agricultural innovation system increase technical efficiency, to better support farmers with strong networks and therefore to contribute towards enhancing productivity, increasing food security and nutrition, diversifying rural livelihoods and reducing poverty. The study performs local innovation networks analysis within a comprehensive local level innovation systems approach to dairy production. The innovation systems approach examines sets of heterogeneous actors who interact in the generation, exchange, and use of dairy-related

[3] Here, by technological innovation, we refer to the development of technology in interaction with the system in which the technology is embedded. Other types of innovations are organizational innovations, which change the organization of production, and institutional innovations, which induce changes in policies and/or norms.

knowledge in processes of social or economic relevance, as well as the institutional factors that condition their actions and interactions (Spielman and Birner, 2008).

The specific objectives, research questions, the hypotheses and the rest of the organization of the dissertation are set forth in the next section.

1.2. Research Objectives, Questions and Hypothesis

The general objective of this study is to investigate the innovation capacity of rural innovation processes to better support farmers with strong networks and therefore greater opportunities to innovate and improve the productivity of dairy production systems in Northwest Ethiopia.

The study has three specific objectives and associated research questions:

1. Understand the innovation systems and networks that influences (impair or support) change in smallholder dairy production system and identify intervention points for strengthening innovation capacity. The associated research questions are:

   (a) Who are the local-level innovation system actors[4] and their extent of diversity in the smallholder dairy production system?

   (b) How actors interact (functioning) in the production, exchange and use of knowledge and information with in the system: who interacts with whom, about what and how? How are ties and relationships maintained?

   (c) How actors respond individually and collectively to technological, organizational and institutional opportunities and constraints: how active is each social actor within the network? Who is the most active social actor within the network? And which social actor has the fastest access to all the actors within the network? Who is the best connected social actor within the network?

[4] Actors are individuals or organizations, in the public or private domain who have the ability to cause change. The public domain includes government and government-based organizations at the local, zonal, region and national level. The private domain includes the private commercial or business sector, community-based organizations such as farmers' association, and 'third sector' organizations such as private development agencies and NGO's.

d) Are there differences in innovation and networks between innovator and non-innovator farmers group and across geographic sites?

2. Investigate the impact of social networks on smallholder dairy technology adoption. We aim at answering the questions:

(a) Which kinds of networks matter for dairy technology adoption?

(b) How do specific networks contribute to innovation processes and enhance adoption of dairy technologies?

3. Examine the extent and determinants of technical efficiencies of smallholder dairy farmers in the context of a comprehensive local-level innovation systems approach to dairy production. Specific questions include:

(a) What are the determinants of technical efficiency?

(b) Which variables have the greatest impact on technical efficiency?

(c) What is the level of technical efficiency?

(d) Are there differences in technical efficiency between dairy technology adopters and non-adopters, men and women smallholder dairy farmers and across districts?

We hypothesized that:

1. Local level innovation system actors who interact in the generation, exchange, and use of dairy-related knowledge, as well as the institutional factors that condition their actions and interaction will contribute to dairy production and productivity.

2. Local-level social networks contribute significantly to smallholder innovation processes by influencing information transfer, and consequently technology adoption by farmers.

3. The different components of the local level agricultural innovation system will significantly affect the technical efficiency of dairy production.

1.3. Organization of the Dissertation

This dissertation is organized in five chapters, including this introduction. Chapter two details the literature review, and discusses the overview of the dairy sector in Ethiopia; the theoretical and analytical frameworks used in the study for each of the three objectives. First, it presents the theoretical and conceptual framework we are following for the analysis of objective one: an agricultural innovation systems (AIS) approach which allows us to explore the capacity to innovate. Second, it describes the theoretical and conceptual framework used for understanding the adoption of modern dairy technology in a network context (objective two). Finally, discusses the theoretical and analytical framework that contributes to technical efficiency analysis (productivity growth) in the context of local-level AIS (objective three).

In Chapter Three, we present the research methodology that addresses description of the study area, survey sampling approaches, the data and description of variables and the empirical models used to estimate results for each of the objectives. In the first part of the empirical model, we present the social network analysis method to analyze the rural (local level) innovation system processes (objective one). It is a two-stage social network analysis method (one refers to the entire network analysis and the other to the centrality analysis) are used to assess the social networks in the dairy production system practiced among smallholder farmers; followed by a framework to analyze the role of social networks on dairy technology adoption (objective 2). It is the target input model which is used to assess a smallholder's use of information about a given technology as the bases to examine the effects that individual and social learning have on a smallholder's decision to adopt a new technology. Finally, a two-step Cobb-Douglas stochastic production function estimation model presented to analyze the technical efficiency of dairy farmers in an innovation system perspective (objective three). The first step involves the specification and estimation of the stochastic frontier production function and the prediction of the technical inefficiency effects. The second step involves the specification of a regression model for the predicted technical inefficiency effects.
Chapter Four presents the results and discussion of all the three objectives. Chapter five presents a summary of conclusions, policy implications, limitations of the study and associated recommendations for further research.

CHAPTER 2. LITERATURE REVIEW

2.1. An Overview of the Dairy Sub-Sector

This section presents an overview of the dairy sector in Ethiopia. It starts by looking at national scenarios and puts the constraints and opportunities for further development.

According to the Ethiopian Livestock Master Plan study (MoARD, 2010) the dairy system of the country can be categorized under five systems of operation; pastoral (traditional pastoral livestock farming), agro-pastoral (Traditional lowland mixed livestock farming), mixed crop livestock system (traditional highland mixed farming), urban and peri-urban (the emerging smallholder dairy farming) and commercial (specialized commercial intensive dairy farming). This approach can be classified broadly into two major systems, namely: (1) The rural dairy system which is part of the subsistence farming system and includes pastoralists, agro-pastoralists, and mixed crop–livestock producers; (2) The peri-urban and urban dairy systems. In another study, on the basis of factors of production, Seré and Steinfeld (1996), classify livestock production systems into modern and traditional. Modern systems have large capital requirements and employ substantial amounts of hired labor, while traditional systems mainly rely on family labor and the extensive use of land. Accordingly, traditional livestock system is the predominant in Ethiopia as well as in the study region.

Ethiopia has 10 million milking cows, which is 20% of the total cattle population. The genetic makeup of the dairy population is over 99% indigenous. Total milk production in 2011/12 reached approximately 3.3 billion liters – an average of 1.54 liters per cow per day over a lactation period of 180 days. From the overall Ethiopian milk production, the rural dairy system, which includes pastoral, agro-pastoral and mixed crop livestock system, contributes 98%, while the peri-urban and urban including the commercial dairy farms produce only 2% of the total milk production of the country. Indigenous stock produce 97% of the milk produced from cattle and the remaining 3% from improved exotic crosses and pure grade cattle (CSA 2012a). Most of the milk produced in the rural dairy system is retained for home consumption and it is non-market oriented. Households consume approximately 85% of the milk produced, 8% of the milk is processed into products with longer shelf life, and 7% is sold (MoARD 2010). This shows that the economic prospects for dairy industry to emerge and develop are rather good both at the smallholder level and on the more commercial level.

According to a study by Tesfaye et al. (2008) the per capita consumption of milk of Ethiopia is the lowest in Africa which is about 23Kg. per annum, while the per capita milk consumption in Africa, on average, is 37.2 kg. The sub-Saharan average is below this, which is 27.5kg. Ethiopia has been consuming on average below the Sub-Saharan level. This indicates Ethiopia has to invest more to tap its potential in milk production and consumption.

In terms of marketing, of the total milk produced in the country only 5% is marketed as processed fluid milk due to the underdevelopment of the infrastructure in rural areas (MoARD 2010). During the last decade the dependency of Ethiopia on imports of milk and milk products has increased. To bridge the gap between demand and supply, dairy imports, primarily powder milk, imports reached a peak of 994,657 kg in 2008 (Land O'lakes, 2010). The value chain encompasses (Fig. 1) all direct and indirect actors from the point of production up to the point of consumption of the dairy products. The direct actors are rural traditional small holder producers, improved market oriented, dairy farmers and dairy cooperatives and Unions, milk collectors, small scale dairy processors, dairy input suppliers, commercial dairy farms, commercial dairy processors, retailers, consumers. Indirect actors and support/service providers are government offices at all levels, dairy and livestock development projects, Non Governmental Organization, producers associations, professional associations, financial institutions are among the list.

Overall, the performance of the dairy sector in Ethiopia has been far from satisfactory. Productivity of the indigenous breed is very low. Farmer's profits remain well below potential due to very poor yields. Further down to the value chain, there are constraints facing the development of the dairy sector which includes: feed supply not adequate, seasonal, inferior quality, high cost and production and distribution not coordinated; low productivity of the dairy herd, short supply of improved dairy breed, and inefficient artificial insemination service; livestock diseases that cause heavy economic losses; weak marketing network, high transaction costs from poor infrastructure, high post-harvest losses, and inconsistency of demand and supply of milk; weak extension service which need more improvement in terms of efficiency and effectiveness; limited capacity of farmers organization (cooperatives) on management and marketing of milk marketing, and shortage of capital; poor credit access to smallholders, cooperatives and unions; lack of coherent national and regional dairy policy, low organizational capacity, ownership & follow-up, coordination and continuity is a problem (MoARD, 2010).

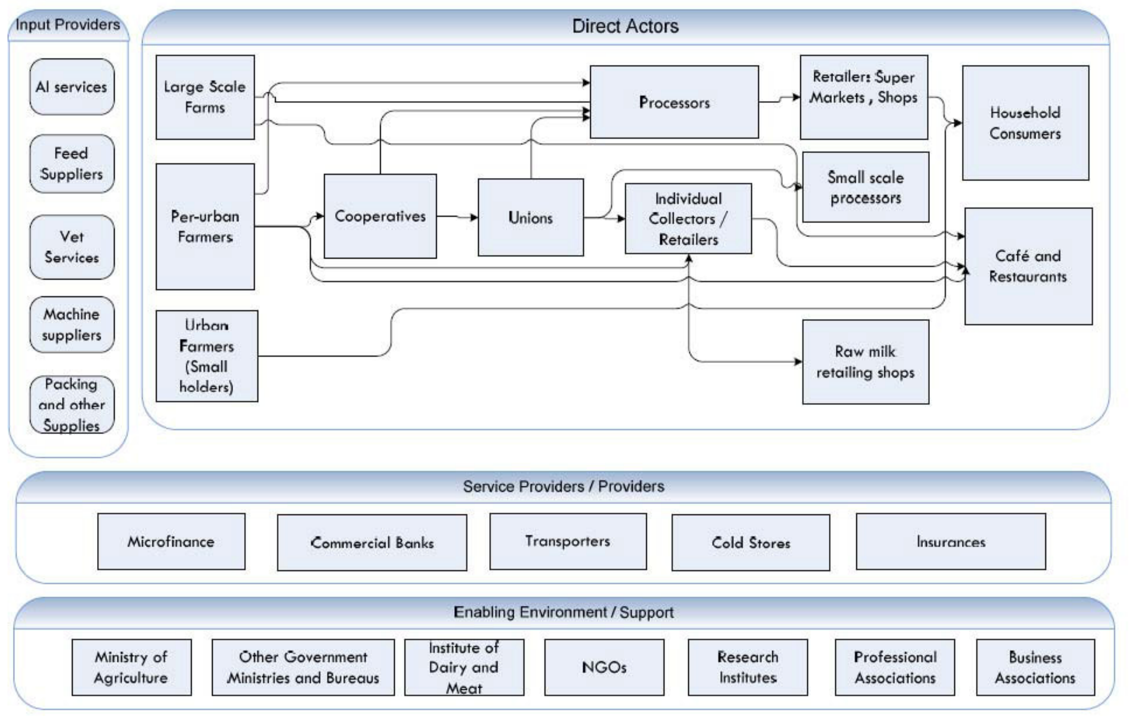

Figure 1. Ethiopian Dairy Value Chain Map of Actors.
Source: Adapted from Land O'lakes (2010)

The opportunities are, however, available for the dairy sector to make greater contribution to rural poverty alleviation, increased food security and improved human well-being: (1) the breeds/types of animals are suitable for the different agro-ecological zones, implying that with clearly defined breeding strategies and sufficient investment, breed improvement could have much impact on the development of the sector; (2) Ethiopia has a large labor force, vast grazing land, and conducive climatic condition for improved forage production, as well as a huge domestic and international community, which would support the intensification and commercialization of livestock production using simple and appropriate technologies; (3)The demand for dairy products in Ethiopia is expected to increase due to the rapidly increasing population with a growing rate of urbanization; (4) proximity to the Middle East, a potentially big market for powder milk and the fact that the animals are fed on natural pastures (Bio) could boost the export market once the production constraints are removed (ADF, 2003). Therefore, any improvements in technological, organizational and institutions through properly channeled innovation systems approach could readily enhance dairy production and productivity.

2.2. Agricultural Innovation System Framework

We begin by rethinking dairy production as part of a bigger dynamic system of livestock innovation. The framework we are following for analysis is an innovation systems approach which allows us to explore the capacity to innovate.

The concept of innovation systems by Hall *et al*. (2008, 2009), Spielman *et al*. (2007, 2008), World Bank (2006a) and Clark (2002) provides an alternative framework to that of the linear technology diffusion model. The latter has been criticized for its failure to understand the source, nature and dynamics of most innovations processes, particularly in the context of developing countries (Edquist 1997).

As an element of the conceptual framework, we focus on innovation systems approach by Spielman and Birner (2008). This approach examines sets of heterogeneous actors who interact in the generation, exchange, and use of agriculture-related knowledge in processes of social or economic relevance, as well as the institutional factors that condition their actions and interactions. In effect, the approach moves our inquiry away from a more linear, input-output model of innovation through research, development, and dissemination, to model of innovation that mirrors a web of related individuals and organizations that learn, change and innovate through iterative and complex processes.

Innovation is defined as the process of creating, accessing and using knowledge and information to create new products, processes, services, etc., that satisfy social and economic goals (Hall *et al*., 2008). The question is partially about developing new knowledge, but it is also about the ability to mobilise available knowledge, and use this knowledge. This shifts the emphasis from technology and agricultural production techniques towards networks, linkages and institutional environments that enable the integration of different knowledge sources, and enable the adaptation of proposed technologies to meet the requirements of the local context.

The innovation system concept is presented as a framework for examining the notion of innovation capacity (Figure 1). The framework is developed by Arnold and Bell (2001) and World Bank (2006a) extended to a sphere of agriculture and provides the four point analytical framework to investigate agricultural innovation capacity. The checklist includes: (1) Actors, the roles they play and activities they are involved; (2) Attitudes (habits) and practices of the main actors; (3) Pattern of interaction; (4) Enabling environment (institutions and policies).

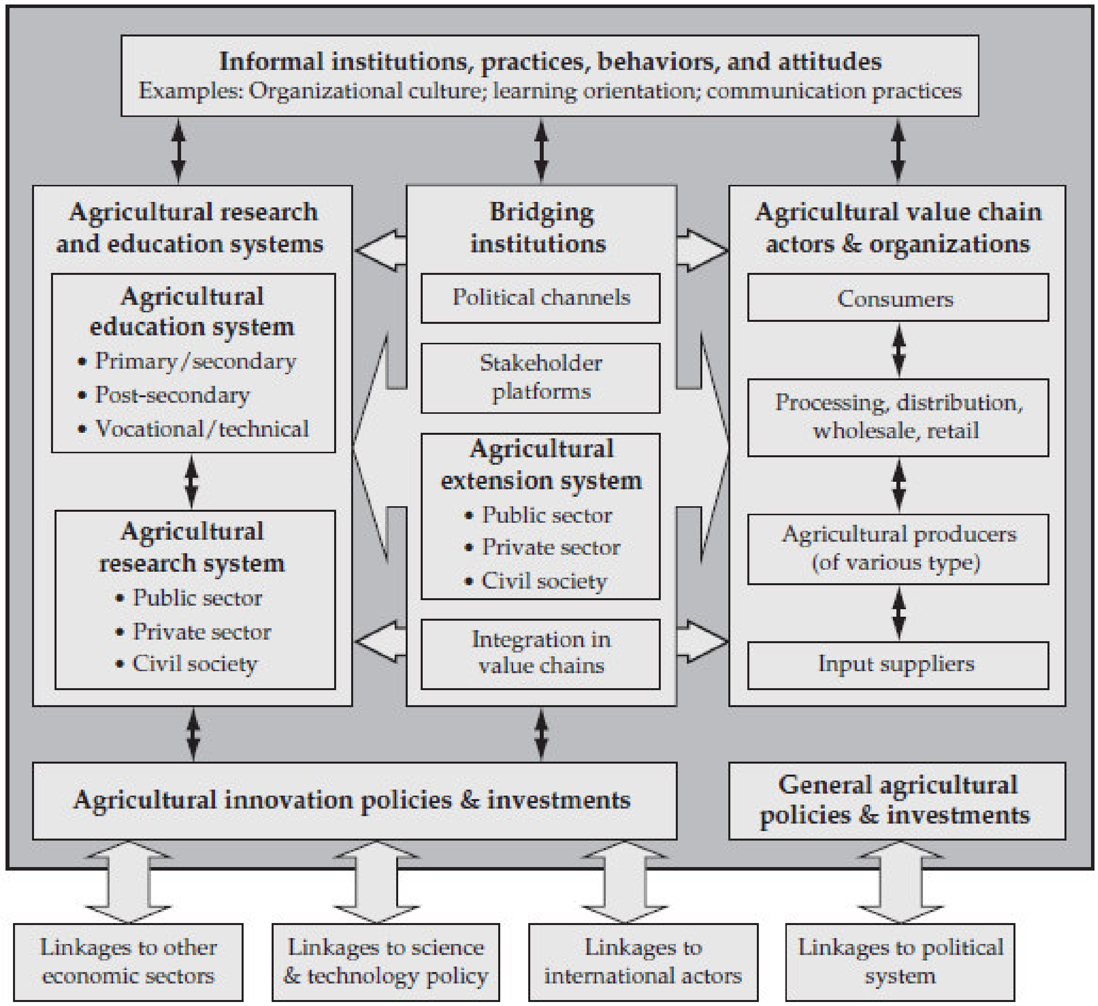

Figure 2. A conceptual framework of National Agricultural Innovation System.
Source: Spielman and Birner (2008) adapted from Arnold and Bell (2001).

Actors are individuals or organizations, in the public or the private domain, that have the ability to cause change. The livestock sub-sector is one of the major contributors to food security and growth within the agricultural sector. The following may be key actors in the system: smallholder farmers, firms that provide inputs and services (such as forage seed, equipment, credit, etc), agro-processing enterprises, organizations that influence policy and provide resources (Bureaus of agriculture, education, finance, industry and trade), market intermediaries (traders, brokers and their associations), research and development organizations (public, private), universities and other institutions of higher learning, organizations that provide information and services (extension and training services, animal health services), farmers associations (cooperatives, unions), religious social organizations, bilateral projects and NGOs that facilitate networking.

Central to the process are the interactions of different people and their ideas (knowledge); the institutions[5] (the attitudes, habits, practices, and ways of working) that shape how individuals and organizations interact; and learning as a means of evolving new arrangements specific to local contexts. The roles of institutions in innovation include "managing uncertainty, providing information, managing conflicts and promoting trust among groups" (Oyelaran-Oyeyinka 2005). Recent innovation capacity studies in Europe (Loorbach 2007), Asia (Spielman and Kelemework 2007; Rist *et al*. 2007), Latin America (Rist *et al*. 2007) and Africa (Rist *et al*. 2007; Spielman *et al*. 2010; Tesfaye *et al*. 2010; Davis *et al.* 2006; Mazur 2006) have all concluded that the innovation systems approach is a useful encompassing framework to orient development strategy.

Explicit in the innovation system concept is the notion that innovations are the product of networks of social and economic actors who interact with each other and, as a consequence of this interaction, create new ways to deal with social or economic processes (Hall *et al.* 2001). Similar to Scott (2000) social networks are conceptualized in this study as relationships among actors. Actors build on connections and better connections create economic opportunity (Krebs and Holley 2002).

Innovation systems can be analysed using methods of social network analysis (SNA) (Spielman et al., 2009). The SNA is a useful tool for investigating social structures. As it is a tool that can be applied in many fields, we study, in particular, its influence in the innovation system. It is useful in understanding and mapping innovation systems because of its analytical focus on relationships and interactions between people and groups, and its ability to capture knowledge flows and other attributes contained within such interactions (Spielman *et al*., 2009). In SNA the nodes of concern are people, groups and organizations and the links may be social contacts, exchanges of information, political influence, money, joint membership in an organization, joint participation in specific events or many other aspects of human relationships (Davis *et al.* 2006). Conceptually key data points in a network are the node (a single actor within a network), the ties (links between the nodes), and the dyad (pairs of actors). Networks potentially offer opportunities for taking advantage of economies of scale and scope as well as for developing capabilities necessary to respond to old challenges of

[5] Institutions are the formal and informal rules (laws and regulations, norms, values, and morals), that shape human behaviour, and the mechanisms (including certain organizations) for their enforcement (North 1990).

underdevelopment and/or emerging new challenges. Networks aim to exploit comparative advantage and maximise spill-over effects.

Interest in SNA has only recently bloomed with the study of innovation systems approach in developing country agriculture (Spielman, 2010). There are, however, few related disciplines that use SNA to examine smallholder innovation systems and processes illustrate the tool's value. Examples include social network effects on the adoption of agroforestry species in southern Ecuador (Gamboa *et al*., 2010); to analyse the agricultural biotechnology policy network (Philipp, 2010); to analyse the management of water resources network for agriculture (Rodriguez *et al.* 2006); the analysis of rural networks in Ethiopian smallholders (Spielman *et al.* 2010); as an analytic tool within integrated pest management stakeholders' practices (Raini *et al*. 2006), building farmers' capacities for networking (Clark 2006), and farmers social learning processes (Conley and Udry 2001).

The innovation systems network study offers a locally relevant architecture that effectively links the different actors within the agricultural innovation system. This new architecture will also address the fundamental institutional and policy issues that currently constrain the emergence of effective agricultural innovation system.

2.3. Role of Social Networks on Adoption Decision

Social networks facilitate information flow, build social capital, confidence and trust and create preparedness for change, lowering barriers to forming new linkages and thus have broader objectives (Hall et al. 2006). Many studies, comprehensively reviewed in Rogers (2003), argue that social networks are vital in technology adoption as networks serve as information channels and as avenues for learning. Moreover, social structure especially in the form of social networks, affects economic outcomes in such a way that it affects the flow and the quality of information (Granovetter 2005; Hartwich and Scheidegger 2010).

Social networks are very important to smallholder, resource-poor farmers, who depend more on informal than formal sources of information, as well as to women farmers, whose information needs are often not addressed by formal extension services (FAO 2011; World Bank 2012). In addition, leveraging farmers' networks would not only be very time efficient, it could also be very cost effective, in the sense that these social structures already exist and would not have to be constructed artificially, as in other extension approaches (Matuschke, 2008). Certainly; several empirical studies exhibit that social networks considerably influence the adoption decision of smallholders (for example, Baerenklau 2005; Bandiera and Rasul 2006; Conley and Udry 2001; Matuschke et al. 2007; Munshi 2004; Spielman et al. 2007). However, early evidence (for example, Alex et al. 2004; Benin et al. 2007) suggests that successes and failures of using social networks to promote technology adoption are often very context specific and that more empirical evidence is needed.

In this research, we follow the framework of Hartwich and Scheidegger (2010) to understand how the connectedness of farmers to different development actors simultaneously influences their decision to innovate (Figure 2). This framework will be used in association with an innovation systems approach (Clark 2002; Hall 2008; World Bank 2006), which will allow us to explore new inroads for the understanding of rural innovation processes, emphasizing in particular the role of social networks on the study of dairy technology adoption.

Innovation occurs in network-like structure of interaction and continuous learning assuring the participation of different actors. Particular to this study, innovation actors in the dairy production system at the local (district and village) levels include primary producers, farmers' cooperatives for input/output marketing; community-based organizations (e.g., work groups, traditional informal organizations at community level); government offices and private firms (e.g., traders).

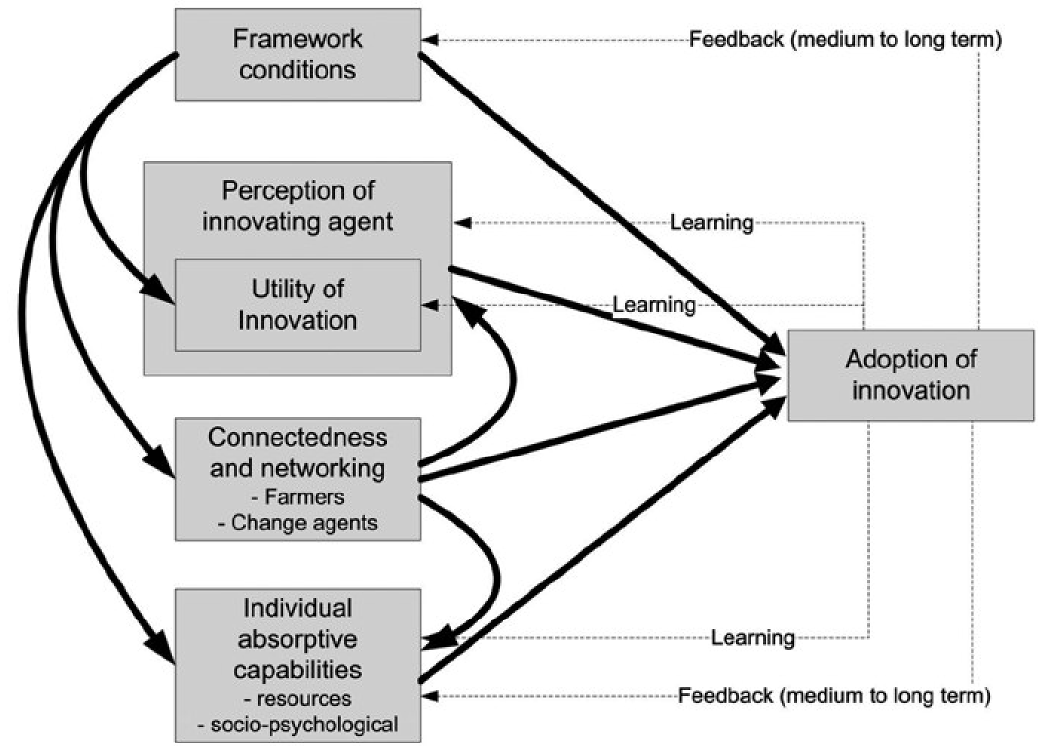

Figure 3. A conceptual framework for factors influencing the adoption of innovation
Source: Adapted from Hartwich and Scheidegger (2010)

Hartwich and Scheidegger (2010) summarized the previously used adoption predictors and have pushed further to incorporate the effects of the farmers' position in networks of communication about the opportunities and usefulness of adopting certain knowledge and technologies including communications among farmers themselves and with many other agents in to the analysis. Lending these new approaches, we provided factors that influence local level innovation in a network context considered in our study: (1) The farmers' individual absorptive capabilities, within which three sets of variables are defined which depend on: resource endowment (e.g. land asset and other asset ownership); socio-demographic factors (e.g. education, age, gender, dependency ratio); and socio-psychological behavior (e.g. attitude to credit); (2) The farmer's connectedness in networking and relationships with other farmers and change agents who provide information on the use of the innovation. Within this component two sets of variables concern: membership in peer-network and membership in non-peer network (e.g. extension, community and market networks); (3) the third component involves characteristics of the local context (village fixed effects) to control for un observables at the village level that may affect adoption. These latter characteristics incorporate three sets of variables: length of growing period; market access and village adoption rate).

2.4. Innovation and Technical Efficiency

Technical efficiency is a measure of a farm's productive performance (Wouterse, 2011; Aigner, et al. 1977; Meeusen and van den Broeck 1977).). In the context of this study, it can be defined as the ability of a smallholder dairy farmer to obtain maximal output from a given set of inputs. Technical inefficiency on the other hand is the deviation of an individual smallholder farm's production from the best practice frontier. The level of technical efficiency of a particular farm is based upon deviations of observed output from the efficient production frontier (Greene, 1993). If the actual production point lies on the frontier it is perfectly efficient. If it lies below the frontier then it is technically inefficient. The distance between the actual to the achievable optimum production from given inputs, indicates the level of production inefficiency of the individual firm (Greene, 1993; Friebel et al, 2003).

We consider local level (district) agricultural innovation system perspective as a theoretical construct that contributes to productivity growth through four main components: knowledge and education, business and enterprise, bridging institutions, and the enabling environment, based broadly on a construct developed by Arnold and Bell (2001) and adapted to the sphere of agriculture and agricultural development by World Bank (2006). In this study the key elements that proxies the local level agricultural innovation system are described as follows. The knowledge and education domain captures the contribution of education to technological change and proxies by education of the household head. The business and enterprise domain captures the set of input-output market actors and activities that leverage dairy production inputs to farmers and milk outputs for markets. Within this component group membership of the household head assumed to proxy the marketing role is included. Bridging institutions represent the domain in which individuals and organizations that leverage public extension services in the innovation process. This component incorporate two variables: extension visit by extension agent and technical training given to the farmer on dairying. Circumscribing these domains are the enabling or frame conditions that foster or impede innovation, including public policies on innovation and dairy enterprise - for example, credit availability, off-farm income opportunity and land availability.

Generally two approaches are used to obtain estimates of farm household efficiency: parametric and non-parametric. The non-parametric approach is implemented using data envelopment analysis (DEA) while the parametric approach uses econometric techniques. These two methods have a range of strengths and weaknesses which may influence the choice of methods in a particular application and the constraints, advantages and disadvantages of each approach have been discussed by Coelli (1996) and Coelli and Perelman (1999). However, it is well documented that the DEA approach works under the assumption of absence of random shocks in the data set. Since farmers always operate under uncertainty, the present study employs a stochastic production frontier approach introduced by Aigner *et al.* (1977); Meeusen and van den Broeck (1977) and refined by Battese and Coelli (1995). Following their specification, the stochastic production frontier can be written as:

$$y_i = f\left(x_i;\beta\right) + \varepsilon \qquad i = 1,2,........N \tag{1}$$

Where y_i is the output of milk for the j^{th} farm, x_i is the i^{th} input used by the j^{th} farm and β is a vector of unknown parameters and ε is a composed error term which can be written as:

$$\varepsilon_i = v_i - u_i \tag{2}$$

Where v_i is a systematic random error which represents random variations outside the control of the farmer such as disease, weather condition, natural disaster, luck, fires, and other exogenous random factors (Jaforullah et al., 1996) and assumed independently and identically distributed with zero mean and constant variance $N\left(0,\sigma_v^2\right)$. The error term u_i is a one sided non-negative term $\left(u_i > 0\right)$ representing the deviations from the frontier production function, which is attributed to controllable factors (technical inefficiency). This one sided error term can assume various distributions such as truncated-normal, half-normal, exponential, or gamma (Aigner et al., 1977; Meeusen and von den Broeck, 1977). However, in this paper it is assumed u_i to be distributed identically and independently half-normal $N\left(0,\sigma_u^2\right)$ as typically done in the applied stochastic frontier literature. Further more, the two components v_i and u_i are also assumed to be independent of each other. For a detailed review of the literature on stochastic production function for developing country agriculture see Bravo-Ureta and Pinheiro (1993), Coelli (1995).

Stochastic production frontier functions have been widely used to assess the economic efficiency of agricultural production in recent years (e.g. Battese and Coelli, 1992; Battese and Coelli, 1995; Battese et al., 1996; Coelli and Battese, 1996; Coelli et al., 1998; Seyoum et al., 1998; Sharma and Leung, 2000a,b; Bravo-Ureta et al., 2001; Chiang et al., 2004; Bozoglu and Ceyhan, 2007; Oladeeebo and Fajuyibge, 2007; Ashagidigbi et al., 2011.

CHAPTER 3. RESEARCH METHODOLOGY

3.1. Study Area

This study was conducted in four selected districts, namely Gondar Zuria, Lay Armachiho, Wogera and Debark in the North Gondar Zone of the Amhara Regional State, which is located in Northwest Ethiopia (Fig. 4).

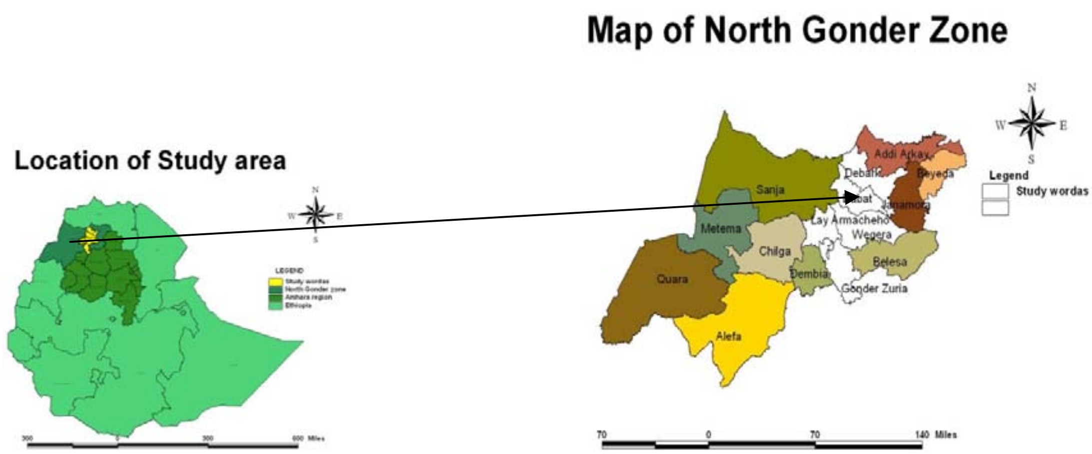

Figure 4. Map of Ethiopia and the study area.
Source: SRMP, North Gondar.

The study focused on innovations that were introduced by the Integrated Livestock Development Project (ILDP) that has been implemented for 10 years (1998-2008) in three phases at 14 districts. ILDP is an Austrian government financed program implemented by the Regional Bureau of Agriculture. The project supports the government's endeavor to improve livestock productivity and income so as to contribute to the food security conditions of the farmers in Northwest Ethiopia. ILDP was involved in implementing an integrated livestock development program via packages of feed, health care delivery, genetic improvement, marketing and capacity building at the smallholder level and impacts on the livelihoods of beneficiary households were indicated to be impressive in different reports (ILDP 2007). Some of the success indicators showed that: (1) up to 0.25 hectare per household was used for improved forage crops; (2) mortality rate of cattle decreased by 3-4% and morbidity rates per animal reduced from 30-50% and (3) milk production increased from 2 liters to 6 liters per day per cow on average. The success of the project can be attributed to, *inter alia,* the targeting, selection of technology, delivery mechanism (extension), input supply and credit schemes, and its attempt to link farmers to markets (ILDP, 2007).

Data for the study was collected in eight villages[6] with in the four districts (Table 1), where the project has been providing rural development support services since 1998. Geographic sites selection for the case study of local-level smallholder dairy innovation systems was done mainly based on the length of time that ILDP had been involved in the districts. The choice is also influenced by the wide agro-ecology representation, agro-potential for future development, accessibility and type of intervention chosen for the study. Table 1 shows the sites selected for in-depth study.

Table 1. Selected sites for in-depth study

District	Village	Livestock/ Technology Package Introduced	Agro-ecological Zone [a]	Development Potential [b]
Gondar-Zuria	1.Tsion 2. Degola	Dairy & Forage	M1, M2	Medium potential, low risk
Lay-Armachiho	3. Kerker 4. Shumara	Dairy & Forage	M1, M2	Medium potential, low risk
Wogera	5.Ambagiorgis 6.Yishakdeber	Dairy & Forage	M2	Medium potential, low risk
Debark	7. Mikara 8. Zebena	Dairy & Forage	M2	Medium potential, low risk

[a] *M1 is hot-to-warm, moist lowlands (1500 – 2500 masl); M2 is tepid-to-cool, moist mid-highlands (2500-3000 masl). Source: MoA (2000).*
[b] *Source: World Bank (2004).*

Considering areas where ILDP has operated for long time eased the understanding of how local-level agricultural innovation systems in dairy production have impacted productivity of farmers and thereby benefit our study. Thus focusing on practices, technologies and knowledge sharing mechanisms by ILDP was important in order to capture the role of local level social networks to innovate.

The development status, potential and opportunities for growth of the study areas are classified under low risk-medium potential districts[7] lying mainly along the high rainfall, western slope of the highlands (World Bank 2004). Ethiopia has high potential for agricultural development and these agro-ecological classifications have important implications for

[6] Village is used in this study synonymous to kebele, which is the lowest administrative hierarchy in Ethiopia. A village administration has an average of 1000 households or 5000 inhabitants.
[7] Areas between 1500 to 2500 meters above sea level, where annual rainfall ranges from 800-1200 mm. Assessment of development status, potential and opportunities for growth are based up on the examination of 51 indicators (World Bank, 2004).

strategies in development of the agriculture sector. The country is devided into 32 major agro-ecological zones grouped under six major categories. The six categories are further divided into three major agro ecological zones which includes moisture reliable, low moisture and pastoral areas as indicated in the figure below (CAADP, 2009).

The study villages have arable land with an average size of household landholdings of 1.86 hectare, and also have a higher level of ownership of livestock, a key component of the highland agricultural production system, with average household holdings of 4.46 Tropical Livestock Unit (TLU) (Table 2). The four districts covering some 54805.6 sq kms, have a population of 7, 956, 910 with an average population density of 145.2 per sq km (CSA 2012b).

Table 2. Dairy technology adoption descriptive statistics for sample villages

Sample Villages [a]	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
HHs in the Village	975	1400	660	561	613	515	890	1388	785	1107	484	501
HHs adopting dairy	117	56	20	112	135	20	80	56	125	89	92	20
-Male adopter HHs	93	53	17	93	118	18	72	45	107	73	81	17
-Female adopter HHs	24	3	3	19	17	2	8	11	18	16	11	3
HHs interviewed	28	28	20	28	28	20	28	28	20	28	28	20
Land holding (ha/ HH)	1.26	2.12	1.69	2.07	2.18	2.13	1.38	1.42	1.83	1.74	2.4	2.07
Livestock (TLU/ HH)	2.93	4.55	7.43	9.84	6.09	4.54	2.82	1.08	4.05	3.36	3.62	3.24
Village adoption rate[b]	0.12	0.04	0.03	0.20	0.22	0.04	0.09	0.04	0.16	0.08	0.19	0.04
Travel distance to nearest market (km)	2	5	8	8	4	9	3	5	5	4	4	9
Length of growing period[c] (days)	150	150	150	165	190	165	270	270	250	250	180	180

[a] Villages are (1) Tsion (2) Degola (3) Ambober (4) Kerker (5) Shumara (6) Juha (7) Ambagiorgis (8) Yishakdeber (9) Sankatikim (10) Mikara (11) Zebena (12) Kino.
[b]Village adoption rate is defined as number of adopting HHs (both male and female) over total number of households.
[c] Length of growing period denotes the agro-climatic potential of an area. The higher the precipitation over potential evapo-transpiration (PPE), the higher the potential for keeping dairy cattle. This is because higher PPE provides good conditions for growing forage, a key input in dairy production.

3.2. Survey Sampling Approaches

This section presents the methodology used for data collection in this study. To undertake the three studies step by step, a multi-visit survey was undertaken in the study Districts. Two visits, six months apart, allowed for data collection.

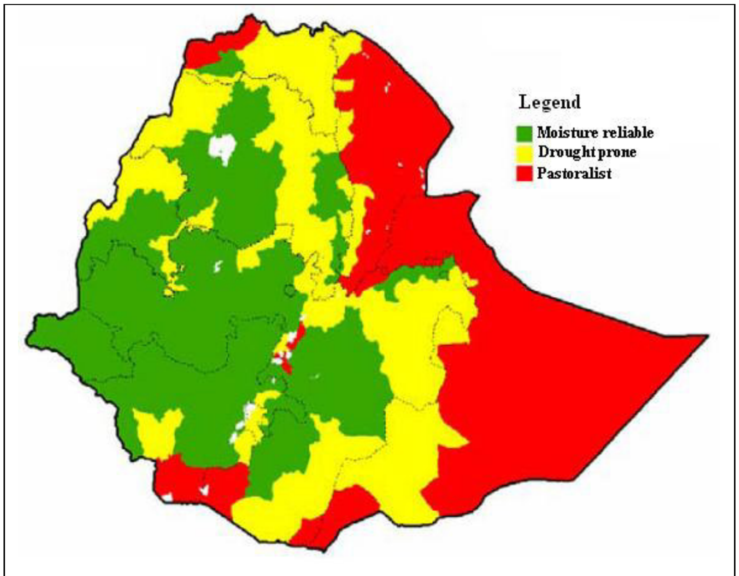

Figure 5. Major agro ecological zones of Ethiopia

Data and information are drawn on two distinct methods. First, 224 households were surveyed in 2010 to shed light on local innovation networks. The surveying process entailed (a) a household survey; (2) a series of focus group interviews conducted in eight separate villages with two groups of five smallholders at each village and (c) key informant interviews with other innovation system actors in the same locality as these sites. The data and information drawn from this process were used to conduct the social network analysis discussed below. Second, a wider sample of 304 smallholders were surveyed in 2011 and the data was used to estimate the impact of social networks on the adoption of dairy technologies and technical efficiency of farmers in the context of local -level innovation system. As will be demonstrated below, the combination of these two methods sheds light on the role and importance of smallholder innovation networks in the study area.

The following are details on the sampling strategy, coverage, and the contents of the survey instrument.

Data collection processes for Objective one:

The SNA of smallholder dairy farmers involved both quantitative and qualitative data and a combination of different approaches such as: (1) household survey; (2) focus group discussion including Venn diagram and Institutional Ranking; and (3) key informant interviews. Prior to the actual data collection translation of the questionnaire into local language, and field visit to pre-test the questionnaire were conducted. Data was collected from July-November, 2010 in the Northwest of Ethiopia.

Household selection

Households were selected through a stepwise process. Within each district, a two stage selection process was followed. First, two villages (case study sites) were purposively selected on the basis of their relative importance in having more project beneficiaries among the first year project districts. Then, a systematic random sampling was employed to select households from each village. The sample size, which mainly depended on the total number of beneficiaries in the sample districts, was determined by using the formula indicated in Jaeger (1984). Accordingly, a total of 224 households were selected from the four districts in eight enumeration sites for household survey.

In each of the target districts and sample villages, representative individual beneficiaries were interviewed by using a semi-structured questionnaire. The questionnaire focused on: (1) the socio-demography of the household (household members, age, sex, educational level, etc.); (2) household assets (land and livestock ownership); (3) access to rural services (extension, saving and credit service); (4) work groups and cooperative membership (how farmers have organized themselves to benefit); (5) participation in the ILDP project (the scope of support extended to farmers from all components of the project); (6) how government/ private service providers are organized to extend support or to administer the program; (7) what challenges they have faced and how these have been surmounted.

Households for further study in the focus group discussions were selected from each village based on a rough index generated from the household survey data. The index was composed of equally weighted values for: (1) adoption of one or more of the improved technology packages introduced by the project calculated by computing the number of technology packages that the household was engaged in, divided by the total number of technology packages). Here, six packages are identified: dairy development, fattening of cattle and small ruminants, sheep and goat production, honey and wax production, poultry production, forage production; (2) adoption of one or more complimentary practices, calculated by computing the number of improved practices applied by the household divided by the total number of practices. Here, two practices are identified: genotype improvement (e.g. improvement of the local breed, implementation of cross breeding) and forage improvement[8] ; (3) household practice of land allocation for forage production and or private grazing calculated as yes= (1) or no= (0); (4) ownership of modern production assets, calculated as the number of modern production assets owned by the household divided by the total number of production assets. Here three assets are identified (e.g. cream separator, milk churner, and aluminum milk container; and (5) contact with agricultural extension services: here two sources were identified (government or farmer development agents).

The five households with the highest index scores and the five households with the lowest index scores were selected for separate focus group interviews and were denoted (for convenience only) as innovators or non innovators, respectively. As shown in Table 3, these groups statistically differed, with innovators exhibiting higher mean values. This approach allowed us to identify groups that, according to household survey data, were using livestock production in general and dairying in particular different from other members in the community, thus offering potentially valuable insights in to the role of smallholder innovation networks.

Table 3. Descriptive statistics for focus group participants

Attributes	Innovators n=40	Non-innovators n=40	Group mean difference test (p-value)
Female participants (%)	20	12.5	
Mean family size (no.)	7.95 (2.3)	6.5 (1.9)	0.0035**
Mean age (years)	47.4 (9.6)	48.4 (11.7)	0.6766
Mean education (years)	3.58 (2.8)	2.25 (2.4)	0.0268*
Mean land ownership size (ha)	1.85 (0.7)	1.48 (0.7)	0.0207*
Mean cross-breed bull (no.)	1.2 (1.0)	0.15 (0.4)	0.0001**
Mean cross-breed cow (no.)	2.5 (1.2)	1.15 (0.8)	0.0001**
Mean land size allocated for forage production (ha)	0.2 (0.2)	0.12 (0.2)	0.0418*
Mean land size allocated as private grazing land (ha)	0.22 (0.3)	0.11 (0.2)	0.0375*

*Notes: Numbers in parentheses show standard deviations. Mean between innovators and non innovators significantly different at confidences interval of *95%; **99%.*

Focus Group Discussion and Semi-structured Interviews

Sixteen focus group discussions (FGD) were conducted (two at each village, one with innovators and one with non-innovators, in eight villages,) composed with five individuals

[8] Forage improvement practice includes (e.g. improving the feed quality of crop residues; natural pasture improvement; forage production through backyard development, under sowing, over sowing, strip planting, sequential cropping, and fodder bank (stored crop residue); improved forages production (e.g. Sesbania sesban, vetch, oats, tree lucern, napier grass, and fodder beet)

each. In each of the target study sites, a checklist of questions was used as a flexible guide for discussions. The pre-tested checklist focused on: (1) identifying source of production knowledge and information; (2) inputs and materials; (3) credit and finance; and (4) market links and price information.

The FGD was followed by a Venn diagramming exercise, followed in turn by an institutional -ranking exercise. Following the FGD interviews at each site, additional semi-structured interviews were conducted with key actors identified by the FGD participants. These include farmer development agents; government development agents; cooperative managers; village officials at local level; experts at agricultural offices and ILDP focal persons at district and zonal level; Bureaus of Agriculture and Amhara Research Institute at regional level. Interviews were guided by questions similar to those posed to PRA participants. Data gathered from the PRA and semi-structured interviews were then used to conduct social network analysis of each site.

Data collection processes for objective two and three:

The surveys were conducted using structured interviews with multistage stratified sampling technique to collect quantitative household level information. Three villages were randomly selected from each of the four districts and therefore the study has been conducted in a total of 12 villages i.e. in addition to the previous eight we add four additional villages.

Data were collected from July to November, 2011 and interviews were conducted with adopters, non-adopters and key informants selected from within the twelve villages in the four districts. Within each district, a two-stage selection process had been followed, selecting first two villages purposively on the bases of their relative importance in having more ILDP project beneficiaries and one non-beneficiary village, and finally randomly selecting households (HHs) within each of the selected villages. The data collection followed a three-pronged approach. First, sample households were randomly selected from a list of 922 farmers who participated in dairy technology interventions (*adopters*, n = 80) from the ILDP project districts. Second, a wider sub-sample of smallholders, that had no direct intervention with the project was randomly selected (*non-adopters*, n = 224) from the same districts. Third, village level data were collected from the key informant interview in the respective villages. The first author and enumerators administered the questionnaires to sample households, as well as a further questionnaire to village leaders (key informants) in each village – a village elder, village administrator, women and youth representatives and extension agent. This provides information on village characteristics. The data and information drawn from these processes were used to analyze the role of social networks in adoption decision with respect to modern dairy production technologies and farmers technical efficiency.

3.3. Data and Description of Variables

3.3.1. Objective one: Innovation Systems and Networks Study

The basic data for the study were typologies of actors and interactions (Annex 1 and 2). Other data collected from the focus group discussion and key informant interview are used to enrich the analysis.

3.3.2. Objective two: Impact of Social Networks on Dairy Adoption

Explanatory variables included in the models were classified in to three groups: household characteristics, specific information on individual networks and village-level characteristics. They are defined in Table 4 along with expected signs on their coefficients.

Prior expectations about the relationship of the explanatory variables to technology adoption are based on the conceptual framework and from previous empirical results. The data are described as follows, with summary statistics given in Table 3 and 5.

Age of the household head proxies for experience and predisposes farmer to better farming techniques through "learning by doing" and better management skills, and is assumed to increase the probability of adoption but at a decreasing rate as the age goes older, such that the estimated parameter is predicted as positive and an age-squared term as negative.

Educational status of the household head provides a dummy measure of whether the household head is literate or not to account for the farmer's capacity for management and for utilizing information relevant to the adoption of the technology. Thus, a positive role of education is hypothesized.

Table 4. Definition of variables in the dairy technology adoption model

Variables	Definition	Expected sign
Household characteristics		
Age	Age of the household head in years	Positive
Literacy	1 if the farmer completes grade 4 formal education; 0 otherwise	Positive
Dependency ratio	Percentage of household members who are economically dependent	Negative
Female head	1 if the household head is female; 0 otherwise	Negative
Land owned	Total land owned by the household in hectares	Positive
Assets owned	The total value of non-land assets of the household in thousands of birr[9]	Positive
Credit accessed	Total amount of loans the household received in a year for dairying in thousands of birr	Positive
Network characteristics		
Peer network	Number of people associated with the household head as a social neighborhood for advice about their economic activities	Positive
Extension network	1 if the household has received a visit on dairying in the last one year; 0 otherwise	Positive
Community network	Number of formal and informal community groups in which the Household is a member.	Positive
Market network	Number of traders that the household has contact with for input/output market	Positive
Village characteristics		
Mean LGP	Average length of growing period of the village in days, which denotes the agro-climatic potential of an area	Positive
Market access	1 if the village has high accessibility(<5 km radius) to a market center; 0 otherwise	Positive
Village adoption rate	Percentage of households adopting dairy technology in the village.	Positive

Household dependency ratio measures the number of household members who are economically dependent on those who are economically active. Here, to be more accurate, we consider the percentage of those who are not involved in actual work than a dependency ratio calculated solely based on the age of household member, wherein members beyond a given age range (both above and below). An increase in dependency ratio reduces the ability to meet subsistence needs, and may also reduce the investment capacity to adopt new technologies. Hence, a negative effect of the variable is expected.

Female-headed household enters as a dummy to control for unique disadvantages relating to the adoption of new technologies without the social capital afforded by a male head of household, and is predicted as negative.

Land asset ownership signify the size of the land owned by the household (measured in hectares), larger landholding implies more land availability for cattle keeping and represents

[9] Birr is the Ethiopian currency, which is equivalent to 0.06 USD, as of October 15, 2011 exchange rate.

both as a measure of the household's stock of productive assets that can support adoption of the technology, and a proxy for the household's asset-based wealth. While both effects are predicted as positive, note that technologies such as dairy are land-intensive with regard to livestock feed production, suggesting a strong relationship with the dependent variable.

Other asset ownership denotes the total value (measured as the natural log of the total assets' Birr value) of livestock, production, household, and house assets owned by the household, and similarly enters as a measure of the household's stock of productive assets that can support adoption of the technology, and a proxy for the household's asset based wealth. To normalize inconsistent estimates of farmers for a value of an asset, we used district-level monthly averages obtained from the office of trade and industry. Both the land and other asset ownership variables are predicted as positive.

Credit measures the total amount of loans the household received in the last one year (also in log values) and indicates the household's access to a financial capital from all possible sources including friends, relatives, money lenders, private traders, government, and NGOs. An estimated coefficient for credit is predicted as positive.

Peer network measures those associated as a social neighborhood to which household members can go to for advice about their economic activities. We assume a positive peer network effect agreeing with Spielman *et al.* (2007), but deviate from Bandiera and Rasul (2006) by omitting estimation of the decreasing returns to network size. As argued by Valente (1995) farmers who are members of a larger network can be assumed to be more exposed to the innovation, and they can assess its suitability from the experience of their network partners and a synergy would be created.

Non-peer network variables, those aims to provide on formal extension supplies, which may have had an impact on the decision to adopt a certain technology, are described as follows. This inclusion allow for incorporating not only smallholders network's but also other sources of information. *Extension network* is a dummy variable that reflects whether the household has received a visit on dairying in the last one year at least once from an extension agent (a development agent). Availability of extension services implies support for the dairy enterprise in general. *Community network* captures the number of formal and informal community groups in which the household is a member including women's association, youth association, water users' group, watershed working group, multi-purpose cooperatives and credit and saving institutions, church/mosque group, funeral groups (idir), work or labour sharing groups (Jigie), and savings and loan type of groups (Iquob). These groups provide linkages to outside actors and a mechanism for information sharing. *Market network* is a number of traders that the household has contact with for input-output market, both inside and outside the village. The estimated coefficients on all non-peer networks are hypothesized as positive.

The study also aimed to address the possibility of endogeneity arising from self selection (where modern dairy adopters participate in networks as a result of their adoption decision) and simultaneity- that is, the fact that a farmer is influenced by his or her group and at the same time influences the group. To do this we assume that the extension network variable is correctly specified given the consistently supply-driven nature of the technology's dissemination. Thus, in the absence of an adequate set of instrumental variables, estimation of the model provides insight into correlation at best, rather than causality.

The mean length of growing period (LGP) denotes the agro-climatic potential of an area and enters as a variable to account for agro-climatic risk of the village. Agro-climatic potential, expressed as precipitation over potential evapo-transpiration (PPE): higher PPE corresponds to more favorable agro-climatic condition for dairy production and associated with adoption. This is because higher PPE provides good conditions for growing forage, a key input in dairy production.

Market access enters as a dummy variable to measure whether the village is characterized by high (distance from homestead <5 km radius) or low (>5 km radius) accessibility to a market center. This measure is a proxy for actual walking distance from a given household to market. Greater distance to market implies reduced access to milk markets, and livestock services, lower milk prices and higher input prices. Closeness to market associated with adoption.

Village adoption rate enters to capture adoption differences between villages. *Village* fixed effects are used in place of these three *village*-specific variables in alternative estimations of the model to control for unobservables at the *village* level that may affect adoption.

Table 5. Descriptive statistics of explanatory variables for adopters and non-adopters of dairy technology

Explanatory variable	Adopters (n= 80)	Non-adopters (n= 224)	Total sample (n= 304)	Group mean difference test

				(p-value)
Individual characteristics				
Age (years)	47.20 (9.50)	48.43 (11.85)	48.11(11.28)	0.4039
Literacy (1/0)	0.90 (0.30)	0.75 (0.43)	0.79 (0.41)	0.2665
Dependency ratio (%)	42.71 (17.44)	38.90 (18.31)	39.90 (18.13)	0.0057**
Female-headed household (1/0)	0.11 (0.32)	0.06 (0.24)	0.08 (0.26)	0.1067
Land owned (ha)	1.64 (0.78)	1.46 (0.82)	1.51(0.81)	0.1476
Assets owned (000 birr)	84.3 (103.6)	43.74 (47.9)	54.4 (69.4)	0.0934*
Credit accessed (000 birr)	1.56 (8.46)	1.06 (3.61)	1.2 (5.3)	0.0001***
Network characteristics				
Peer network (no.)	4.14 (1.67)	3.37 (1.28)	3.57 (1.43)	0.0001***
Extension network (no.)	0.89 (0.32)	0.29 (0.46)	0.45 (0.50)	0.0001***
Community association network (no.)	3.85 (1.61)	3.13 (1.41)	3.32 (1.50)	0.0002***
Market network (no.)	1.68 (1.44)	1.17 (1.32)	1.30 (1.37)	0.004***
Village characteristics				
Mean LGP (days)	202.75 (49.50)	180 (52.08)	179.90 (52.13)	0.3240
Market access (1/0)	0.90 (0.82)	0.70 (0.55)	0.75 (0.64)	0.0160**
Village adoption rate (%)	12.25 (6.80)	10.29 (6.83)	10.80 (6.88)	0.0280**

Note: Numbers in parenthesis show standard deviations. Significantly different at *90%, **95% and ***99%.

Table 5 provides the descriptive statistics of the variables for adopters and non-adopters of dairy technology. Characteristics of households such as dependency ratio, assets owned and credit accessed show significant differences across the groupings. On average, dairy farmers have 48 years of age, 79 % can read and write, 8% are female headed and have nearly 40% economically dependent family members. More households who own assets such as land, non-land asset and having credit access belong to the technology-adopter group. Network characteristics show significant difference towards technology adopters. Farmers who are adopting dairy technology are members of a larger peer and community networks and have better access to extension services and markets. Village characteristics included in the model are more favorable to technology adopters in all aspects.

3.3.3. Objective three: Innovation and Technical Efficiency

The data collected are cross-sectional data obtained through the above mentioned procedure. The questionnaires were administered to dairy farmers and were designed to elicit information on the socio economic characteristics of the respondents and also on the operational systems adopted. Details of all variables are presented in Table 6.

Table 6. Description of output, input and technical inefficiency variables

Variables	Description	Expected

		sign
Ln output (Y)	Natural log. of household total milk output in Birr[a]	
Inputs		
Ln roughage	Animal feed intake in kg (produced in the farm)	+
Ln concentrate	Animal feed intake in kg (purchased industrial by-product)	+
Ln labor	Number of adults working in the farm (ages between 15-64)	+
Ln health	Veterinary service expense in Birr	+
Ln breeding cost	Breeding service expense in Birr	+
Ln hay	Animal feed expenditure in Birr (purchased feed)	+
Inefficiency variables		
Age	Age of the household head in years	-
Age^2	A proxy for years of farming experience of the household head	+/-
Family size	Number of family members in the household	-
Education	Years of formal schooling of the household head	-
Farm size	Total land owned by the household in hectares	-
Credit availability	1 if the farmer gets credit in the production year; 0 otherwise	-
Extension visit	Number of times the household visited for advice by the extension agents during the production year	-
Training	1 if the household attended any dairy production training sessions; 0 otherwise	-
Off-farm income	1 if the household gets income from sources other than farming; 0 otherwise	-
Group membership	1 if the household is a member of any kind of farmers' group; 0 otherwise	-

Note: A negative sign in the inefficiency variables indicates a positive impact on efficiency

A priori expectations about the relationship of the variables used in determining the factors influencing technical efficiency are based on the analytical framework and from previous empirical results. The data are described as follows:

In the production function models, the dependent variable, *output (Y)*, is the natural logarithm of the annual milk produced per farm measured in the value of total milk production in Ethiopian Birr. Average market price of the districts is used to estimate output values.

The inputs are: (1) produced on farm dairy feed (*roughage*) measured in terms of the quantity (kg) of total fed to milking cows in the farm in a given year; (2) purchased dairy *concentrate* feed measured in terms of the quantity (kg) of total fed to cows in the farm in a given year; (3) family *labor* measured in number of persons working in the farm; (4) animal expenses consisting of *veterinary medicine*, *breeding services* and supplementary feed cost (*hay*). The estimated coefficients on all inputs are hypothesized as positive. Although accurate data on such milk production inputs are not easily obtainable in the Ethiopian traditional agricultural sector in general because of measurement problems, an endeavor was made to reduce the error of margin. We first collect the data (for example, number of hips of roughage produced on farm) subjectively from the holder and then recorded after correcting it with the agreed conversion rate into kilogram with the field experts in each village.

The *inefficiency variables* that were used to explain the character and performance of a given dairy farmer in the study area were classified in to two groups: (1) household characteristics; and (2) factors that can reflect (proxy) the capacity of the local level agricultural innovation system (AIS).

They are described as follows: of the household characteristics, *Age of the household head* proxies for experience and predisposes farmer to better farming techniques and is assumed to increase the productivity of the farm and the higher the *farmers' experience*, the greater the technical efficiency was assumed, such that the estimated parameter is predicted as positive for both age and age squared term. *Family size* was hypothesized to have positive effect to the technical efficiency, because bigger household size could mean a more secure labor source for livestock production. Of the variables that proxy local level agricultural innovation system, *Education* was considered as the number of years of formal schooling and was supposed to have positive relationship with level of efficiency. Availability of *credit* in time would facilitate farmers to procure inputs timely thereby increasing productivity and decreasing inefficiency. Regular *visits of an extension agent* would spur farmers to increase the efficiency. Access to *technical trainings* was hypothesized to reduce the inefficiency. It was assumed that the farmer with *off-farm income* augments its access to a financial capital to purchase inputs, which lead to higher efficiency. *Group membership* was considered as a mechanism for information sharing and makes members more efficient than the non-members. The larger the *farm size (land)* was hypothesized to have positive effect to the technical efficiency because farmers may have more fodder production to feed their animals and maintain the productivity of the farm. The estimated coefficients on all inefficiency variables are, therefore, hypothesized as positive.

Characteristics of sample farmers

Table 7 presents the descriptive statistics of dependant and independent variables used in the stochastic frontier production analysis and on the determinants for the dairy farm household efficiency analysis. The data set contains information of 304 sample households (281 men and 23 women) and the average age of a household head is 48 years. The average experience of a farmer in dairy farming is 23 years, but farmers have experiences ranging from 5 to 60 years. On average, dairy farmers have 5 household members, 4 years of formal schooling, and own

1.51 hectare of land. Of the 304 farmers, 63% have attended technical training on dairying, 42% and 22% have had access to credit and off-farm income, respectively, and 88 % are members at least in one farmers group. On average, mean milk output value in the study area is 2321 Birr, with a very high variation among farms. Farmers used on average 2230 kg of roughage, 275 kg of concentrate, and hay at a value of birr 971 per farm, but the variation among farms is quite large.

The descriptive statistics of variables for adopters and non-adopters show that there is mean output and input use difference. This is because adopters of dairy technology have a higher use of land and intermediate inputs to increase productivity. The mean output of milk for farmers within the adopters group was about nearly three-fold than for non-adopter farmers. The roughage, concentrate, health, breeding and hay used by the farmers within the adopters was about 35%, 156%, 11%, 100%, 78% greater than that used by non-adopters.

Table 7. Summary statistics of the variables for dairy farmers 2010/11

Variables	Dairy tech. adopters		Dairy tech. non-adopters		All respondents	
	Mean	Range	Mean	Range	Mean	Range
Milk output (Birr)	4354(5003)	0-30000	1595(2940)	0-32000	2321	0-32000
1. Inputs						
Roughage (kg)	2759(2050)	0-10000	2041(3104)	0-40000	2230	0-40000
Concentrate (kg)	500(1044)	0-7200	195(370)	0-2400	275	0-7200
Labor (man days)	4(2)	2-8	4(2)	1-10	4	1-10
Health expense(Birr)	120(105)	0-500	108(106)	0-720	111	0-720
Breeding expense(Birr)	14(36)	0-300	7(14)	0-74	9	0-300
Hay purchase(Birr)	1433(1506)	0-7000	806(1587)	0-13500	971	0-13500
2. Inefficiency factors						
2.1. Household characteristics						
Age	47.2(9.5)	28-75	48.4(11.9)	22-83	48.11	22-83
Experience in farming (years)	23.17(9.6)	8-56	24.85(12.2)	5-60	24.41	5-60
Family size (no.)	7.36(1.75)	4-11	6.76(1.8)	2-12	6.92	2-12
2.2. Proxy factors to AIS						
Education (years)	4.54(2.27)	0-11	3.55(2.66)	0-12	3.81	0-12
Farm size (ha)	1.64(0.78)	0-3	1.46(0.82)	0-3.75	1.51	0-3.75
Credit availability (1/0)	0.4(0.49)	0-1	0.43(0.5)	0-1	0.42	0-1
Extension visit (no.)	2.93(1.3)	1-5	2.69(1.16)	1-5	2.75	1-5
Training (1/0)	0.66(0.48)	0-1	0.62(0.49)	0-1	0.63	0-1
Off-farm income (1/0)	0.28(0.45)	0-1	0.2(0.4)	0-1	0.22	0-1
Group membership (1/0)	0.96(0.19)	0-1	0.85(0.36)	0-1	0.88	0-1

Note: Standard deviations are given in parenthesis.

Characteristics of both household related variables (age, farmers' experience in dairying and household size) and local level agricultural innovation system indicators such as education, farm size, number of extension visit, those participated in technical training, off-farm income availability and membership in a farmers group vary slightly across groupings, adopters exhibit the highest. More non-adopters (43%) than adopters (40%) reported having credit access.

3.4. Empirical Models

3.4.1. Objective one: Social Network Analysis

In this study the SNA is used to analyze the social networks in the dairy production system practiced among smallholder farmers. The analysis of local network data generally follows a sequence of steps that aim at identifying typologies of actors and interactions. The first step involves two different types of analysis. One refers to the entire network analysis and the other to the centrality analysis (Wellman 1992).

The entire network analysis examines the structure of social networks (including groups or clusters), as well as the networks' composition, functioning and links to external situations. With this analysis it is possible to examine questions such as: who interacts with whom, about what and how? How are ties and relationships maintained, or changed over time? The approach to the entire network analysis focused on the description of the structure of the local network through the examination of the size, density and cohesion of the network.

The centrality analysis is the most important way of identifying the actors that play the most relevant roles within the network and refers to the extent to which a network revolves around a single node (Everett and Borgatti 1999). Centrality is an attribute of the actors in a network that refers to the structural position of an actor within the network. Measuring the centrality of different actors is a way of assessing the importance and influence of an actor with in the network. According to Freeman (1979), the most important measures of centrality are degree centrality, closeness centrality and betweenness centrality. Degree centrality allows the following questions to be answered: How active is each social actor with in the network? Who is the most active social actor within the network? Closeness centrality allows the following questions to be answered: who is the social actor with fastest access to all the actors within the network? Betweenness centrality allows the following question to be answered: Who is the best-connected social actor within the network?

Definitions of the variables (elements) used in the SNA are presented in Table 8. Most of their definitions are adapted from Scott (2000) and regarding the mathematical formulas behind them, consult Scott (2000) for further details.

Data Analysis

Descriptive statistics were done using SAS 9.2 software package (SAS Inc. 2009). Qualitative data (80 primary documents) from FGD and KII interviews were transcribed and later coded with Atlas.ti 6.2 software (Atlas.ti 2010). SocioMetrica VisuaLyzer 2.0 (VisuaLyzer 2007) was employed to look at the data from the PRA exercise and key informant interviews applying social network analysis.

Table 8. Definition of the variables (elements) used in the social network analysis

Element	Definition
Node	A single actor (any individual, organization, or other entity of interest) with in a network
Tie	Interconnections between actors
Directed Tie	An ordered set of two nodes, i.e., with an initial/source and a terminal/destination node.
Ego	Actor of interest within a network
Alter	Node directly connected to an ego
Ego network	Network that only shows direct ties to the ego and not between alters
Dyad	Pair of nodes linked by a tie
Network	Graphical representation of relationships that displays points to represent nodes and lines to represent ties; also referred to as a graph
Network size	Total number of nodes in a network
Network density	Nodes that are actually tied as a proportion of all possible ties in a network. When density is close to 1.0, the network is said to be dense, otherwise it is sparse.
Centrality	Measure of the number of ties that a node has relative to the total number of ties existing in the network as a whole; centrality measures include degree, closeness, and betweenness.
Degree	Total number of ties a node has to other nodes. A node is central, when it has the higher number of ties with other nodes.
In-degree centrality	Number of ties received by the node. The in-degree of an actor is an index of prestige /indicate its importance/.
Out-degree centrality	Number of ties initiated by the node. The out-degree is usually a measure of how influential the actor may be.
Closeness	Measure of reciprocal of the geodesic distance (the shortest path connecting two nodes) of node to all other nodes in the network. A node is "close" if it lies at short distance from many other nodes (as in being physically proximate).
Betweenness	Number of times a node occurs along a geodesic path. It is a node that can play the part of a liaison or broker or gatekeeper with a potential for control over others.
Core	Cohesive subgroup within a network in which the nodes are connected in some maximal sense
Periphery	Nodes that are only loosely connected to the core and have minimal or no ties among themselves

Source: Authors; Scott (2000), Hanneman and Riddle (2005), Wasserman and Faust (2005) and Spielman et al (2010).

3.4.2. Objective two: Target Input Model

Here we portray a standard target input model with Bayesian updating that incorporates the learning behavior of innovative farmers to learn about the parameters of a new technology based on Bardhan and Udry (1999) to capture the relationship such social learning creates between a farmer's adoption decision and those of his network. With such a modeling framework, it is assumed that farmers do not know the optimal input level associated with a new technology. After the initial productivity and income gains as a result of the new intervention, farmers update their beliefs on the optimal input level by combining the experiences of the past season with the experiences from all other pervious periods. The model also assumed that farmers update their beliefs by learning from experiences of neighboring farmers. In social learning, individuals learn by doing (i.e., their own experiences), by observing others (i.e., learning from others), or both (Bandiera and Rasul 2006; Hogset 2005; Monge et al. 2008; Spielman et al. 2007).

The presentation of the model discussed here closely follows that in Bandiera and Rasul (2006) and Spielman et al. (2007) which has been used to study a smallholder's use of information about a given technology as the basis to examine the effects that individual and social learning have on a smallholder's decision to adopt a new technology.

3.4.2.1. Modeling estimation of the target input model

Assume that smallholder i in period t produces some output q_{it} which declines in the square of the distance between the actual inputs used (k_{it}) and some uncertain target input level ψ_{it}; which can be expressed as

$$q_{it} = 1 - (k_{it} - \psi_{it})^2 \tag{1}$$

Suppose that the target input level (ψ_{it}) is not known by smallholder i at the time the input is applied. After the inputs are applied and the output is realized, the smallholder updates his beliefs about the target input level.

Let us assume ψ^* denote the average optimal target input level. To maximize output, the smallholder attempts to gather information that improves his estimate of this optimal target input level. The smallholder's target input level fluctuates around ψ^* such that

$$\psi_{it} = \psi^* + \varsigma_{it} \qquad (2)$$

Where ς_{it} denotes transitory shocks to the optimal target input and is normally distributed with a mean of zero and known variance $\left(\varsigma_{it} \sim \text{i.i.d.N}\left[0, \sigma^2_{\psi}\right]\right)$, implying that expectations of the stochastic term equals zero, or $E_t\left(\varsigma_{it}\right) = 0$.

In period t, smallholder i has beliefs about ψ^*. We assume that his beliefs are normally distributed $\left(N\left[\psi^*, \sigma^2_{\psi it}\right]\right)$ and that fluctuations around ψ^* are reflections of individual-specific and/or time-specific factors.

We make a simplifying assumption that the input is costless, such that the i^{th} *smallholder's profit is* his output $\left(q_{it}\right)$ multiplied by some constant price $\left(p\right)$ which is normalized to 1. The i^{th} smallholder's expected output is thus

$$E_t\left(q_{it}\right) = 1 - E_t\left[\psi_{it} - E_t\left(\psi_{it}\right)\right]^2 = 1 - \sigma^2_{\psi it} - \sigma^2_{\varsigma} \qquad (3)$$

Intuitively, smallholder i's expectations of his output (a) increase with the certainty of his expectations about applying inputs at the optimal target level; and (b) decrease with increases in the variance of transitory shocks to the optimal target input level.

3.4.2.2. Modeling the social learning

An important question remains to be addressed in the model described above: how do smallholders form their expectations? Here, we display how individual and social learning processes affect technology adoption.

Proposition 1. Smallholders learn by doing. Suppose that smallholder i learns about the optimal level of input use by inferring from his observations of output. In period $t-1$, the variance of smallholder i's prior belief about ψ^* is $\sigma^2_{\psi i,t-1}$. Once the smallholder has observed ψ_{it} in time period t, he updates his beliefs about the variance of ψ^* such that

$$\sigma^2_{kit} = \frac{1}{\frac{1}{\sigma^2_{\psi i,t-1}} + \frac{1}{\sigma^2_{\varsigma}}} \tag{4}$$

based on the application of Bayes's rule (Bayes's Rule demonstrates how an initial belief about hypothesis A can be updated in the light of new evidence B. Specifically, a posterior belief about the probability of hypothesis A conditional to hypothesis B $[P(A/B)]$ is calculated by multiplying our prior belief $P(A)$ by the likelihood $P(B/A)$ that B will occur if A is true, or $P(A/B) = \frac{P(B/A)P(A)}{P(B)}$. By defining $\rho_0 = 1/\sigma^2_{\varsigma}$ as the precision of the information generated by the i^{th} smallholder's own trial, and $\rho_{i0} = 1/\sigma^2_{\psi i0}$ as the precision of the i^{th} smallholder's initial beliefs about the true value of ψ^*, then

$$\sigma^2_{kit} = \frac{1}{\rho_{i0} + I_{t-1}\rho_0} \tag{4´}$$

where I_{t-1} is the number of trials i has with the new technology on his own farm between periods 0 and $t-1$. Further substitution yields

$$E_t(q_{it}) = 1 - \frac{1}{(\rho_{i0} + I_{t-1}\rho_0)} - \sigma^2_{\varsigma} \tag{3´}$$

From this equation, we find that the smallholder's expected output is an increasing function of the number of trials he has with the new technology, i.e., learning by doing, or

$$\frac{\partial E_t(q_{it})}{\partial I_{t-1}} = \frac{\rho_0}{(\ \rho_{i0} + I_{t-1}\rho_0)^2} > 0 \tag{5}$$

We hold off on further differentiations until we are able to construct a more complete model of the smallholder's social learning process.

Proposition 2. Smallholders learn from others. Suppose that smallholder i is a member of a social network $n(i)$, the members of which share information with i at no cost to either i or any other member. With this assumption, the farmer now incorporates inferences he/she makes about trials undertaken by members of his network *in addition to* his/her inferences about his own trials. Thus, Equation (5) becomes

$$\sigma^2_{kit} = \frac{1}{\rho_{i0} + I_{t-1}\rho_0 + n(i)_{t-1}\rho_0} \tag{6}$$

This implies that smallholder i's expected output is dependent on inferences from his trials *and* his inferences from the trials of his network members, or

$$E_t(q_{it}) = 1 - \frac{1}{\rho_{io} + I_{t-1}\rho_0 + n(i)_{t-1}\rho_0} - \sigma^2_{\varsigma} \tag{7}$$

Proposition 3: Learning affects expected output. Partial differentiations of Equation (9) obtain the following results:

The i^{th} smallholder's expectations of his output are increasing in the use of the new technology by a member of his social network, implying that social networks generate a positive learning externalities, or

$$\frac{\partial E_t(q_{it}, n(i)_{t-1})}{\partial n(i)_{t-1}} = \frac{\rho_0}{(\rho_{i0} + I_{t-1}\rho_0 + n(i)_{t-1}\rho_0)^2} > 0 \tag{8}$$

Three points are of note. First, the i^{th} smallholder's expectations of his output are increasing in the precision of his own initial information relative to the information obtained from his social network

$$\frac{\partial^2 E_t\left(q_{it}, n(i)_{t-1}\right)}{\partial \rho_{i0} \partial n(i)_{t-1}} < 0 \qquad (8')$$

Second, the i^{th} smallholder's expectations of his output are increasing in the precision of initial information obtained from his social network, implying that the learning externalities vary across networks.

$$\frac{\partial^2 E_t\left(q_{it}, n(i)_{t-1}\right)}{\partial \rho_0 \partial n(i)_{t-1}} < 0 \qquad (8'')$$

Third, information acquired from learning by doing and learning from others are substitutes for each other.

$$\frac{\partial^2 E_t\left(q_{it}, n(i)_{t-1}\right)}{\partial I_{t-1} \partial n(i)_{t-1}} < 0 \qquad (8''')$$

3.4.2.3. Modeling the adoption decision

We now consider the smallholder's technology adoption decision. We denote smallholder i's decision to adopt the technology in time period t as $a_{it} = 1$, and $a_{it} = 0$ otherwise. Smallholder i does so with full knowledge of the riskless return $\left(\bar{q}\right)$ to his existing technology. The smallholder's decision to adopt depends on his assessment of the future stream of profits $\left(V_t\right)$ from period t to T, or

$$v_t\left[I_{t-1} n(i)_{t-1}\right] = \max_{a_{is} \in \{1,0\}} E_t \sum_{s=t}^{T} \delta^{s-t} \left\{ \left(1 - a_{is}\right)\bar{q} + a_{is} q_s \left[I_{s-1}, n(i)_{s-1}\right] \right\} \qquad (9)$$

where $I_{s-1} = \sum_{t=0}^{s} a_{is}$ denotes the total number of trials conducted by i through period s; $n(i)_{s-1}$ is the total number of trials conducted by $i's$ social network over the same period; and δ is the discount rate. Smallholder $i's$ future stream of profits can thus be represented as

$$V_t\left[I_{t-1}n(i)_{t-1}\right] = \max_{a_{it}\in\{1,0\}}(1-a_{it})\bar{q} + a_{it}E_t q_t\left[I_{t-1}, n(i)_{t-1}\right] + \delta V_{t+1}\left[I_t, n(i)_t\right] \qquad (9')$$

The smallholder adopts the technology in period 0 if the expected profit stream of the new technology exceeds the expected profit of the existing technology, or

$$E_0 q_0\left[0, n(i)_0\right] + \delta V_1\left[1, n(i)_0\right] \geq \bar{q} + \delta V_1\left[0, n(i)_0\right] \qquad (10)$$

Two further assumptions should be noted here. First, the new technology is considered to be an absorbing state, once the smallholder adopts the technology, hence he does not switch back. Second, the adoption of the new technology may occur even when the existing technology is more profitable.

3.4.2.4. Modeling the opposing network effects

The derivative of the net gains from adopting in period 0, (equation 10) with respect to the total number of trials undertaken by smallholder i's social network is

$$\frac{\partial E_0 q_0(0, n(i)_0)}{\partial n(i)_0} + \delta \frac{\partial\{V_1[1, n(i)_0] - V_1[0, n(i)_0]\}}{\partial n(i)_0}$$

$$= \frac{\rho_o}{(\rho_{i0} + n(i)_{t-1}\rho_o)^2} + \delta \sum_{s=1}^{T} \delta^s \left\{ \frac{\rho_o}{(\rho_{i0} + s\rho_o n(i)_0 \rho_o)^2} - \frac{\rho_o}{(\rho_{i0} + (s-1)\rho_o n(i)_0 \rho_o)^2} \right\} \qquad (11)$$

As expected, this implies that smallholder $i's$ decision to adopt is positively related to the number of trials undertaken by his social network (the learning externality effect). However, this also implies that smallholder i's decision is negatively related to the number trials undertaken by his social network because the value of information from his own adoption is lower as more network members adopt. In other words, as more network members adopt, it makes more sense for the smallholder to learn from the network rather than undertake his own trials, i.e., a strategic delay effect.

Based on the above framework of learning, the authors estimated the following equation:

Let a_{iv}^{*} denote the present value of the net gains to smallholder i in *village* v from adopting modern dairy technology. We can define the present value of the net gains to smallholder i in period 0 as

$$a_{iv}^{*} = a[n(i)X_{v}, Z_{v}, u_{iv}] = f[n(i)] + aX_{i}^{0} + \beta Z_{v} + u_{iv} \qquad (12)$$

where the adoption decision of individual i in village v was assumed to depend on the information available to smallholder i about the new technology from his social network $n(i)$; as well as X_{v} a vector of individual characteristics describing smallholder i; and a vector describing common observable characteristics (village fixed effect) Z_{v} across area v. Term u_{iv} was defined as an error term and was assumed to be normally distributed and uncorrelated with any of the variables. We specify the smallholder's adoption decision as a discrete choice,

$$a_{iv} = 1 \; if \;\; a_{iv}^{*} > 0$$

$$a_{iv} = 0 \quad otherwise$$

The probability (P) that the i^{th} smallholder adopts the technology is thus given by

$$P(a_{iv} = 1) = P(u_{iv} > -\{f[n(i)] + \alpha X_{i}^{0} + \beta Z_{v}\}) \qquad (13)$$

Depending on the availability of data and information, two approaches to data analysis on the impact of social networks on adoption in developing country agriculture are possible (Hartwich and Scheidegger 2010, Matuschke 2008): (1) Social network analysis (SNA), which is the formal analysis of relationships among agents, groups, or entities using relational data (Crona and Bodin 2006; Darr and Pretzsch 2007; Hartwich *et al.* 2007; Raini *et al.* 2005); (2) Economic approaches to network analysis, assuming that individual decision-making processes and economic outcomes are correlated with the behavior of other agents

(Bandiera and Rasul 2006; Conley and Udry 2001; Moser and Barrett 2006; Spielman *et al.* 2007). Such studies are using individual, village level and social network variables and represented by the proxies that were used for estimating network effects. Accordingly, we used the latter approach to network data analysis.

Adoption is measured as a dichotomous (binary) variable: 1 if the household owns and uses modern dairy production system (i.e. improved dairy breed in association with improved feed and management practices) for milk production, 0 otherwise. Insufficient heterogeneity and indivisibility in the number of improved breed dairy cows owned and used by households in the sample rules out the possibility of an alternative Tobit estimation based on adoption intensity.

We estimate Equation 12, substituting a_{iv} for a_{iv}^{*} , with a probit regression in which adoption is specified as a function of these variables in the form:

$$\begin{aligned} a_{iv} = {} & \beta_0 + \beta_1(age) + \beta_2(age^2) + \beta_3(Literecy) + \beta_4(Female) + \beta_5(Dependency) + \\ & \beta_6(Land) + \beta_7(\ln Assets) + \beta_8(\ln Credit) + \beta_9(Peer) + \beta_{10}(Non - peer) + \\ & \beta_{11}\left(\overline{LGP}\right) + \beta_{12}(Market) + \beta_{13}(Adoptionrate) + u_{it} \end{aligned} \tag{14}$$

Estimation of Equation (14) generates parameters that are reported as the marginal effects of the given variable on the probability of adoption.

After setting up the model, we proceeded in three steps in order to additionally account for robustness. In our first estimation we include the baseline estimation of adoption (Model 1) using the two variables of interest: peer network and non-peer network. In the second estimation (Model 2) we present a more complete estimation of Equation (14). In the third estimation (Model 3) we did an estimation of Model 2 with *village* fixed effects, (agro-climatic, market access and village adoption rate) as control variables introduced in the previous models.

3.4.3. Objective three: Stochastic Frontier Analysis

As in Battese and Coelli (1995), this study follows a two step estimation model. The first step involves the specification and estimation of the stochastic frontier production function and the prediction of the technical inefficiency effects, under the assumption that these inefficiency effects are identically distributed. The second step involves the specification of a regression model for the predicted technical inefficiency effects.

Step 1. Estimating the Stochastic Frontier

We introduce here the Cobb-Douglas form of a standard stochastic frontier production function model. The Cobb-Douglas functional form is chosen because it provides an adequate representation of the production process, since we are interested in an efficiency measurement and not an analysis of the production structure (Taylor and Shonkwiler, 1986). In addition, the Cobb-Douglas (CD) functional form (in spite of its restrictive properties) is used because its coefficients directly represent the elasticity of production. It is also widely applied in farm efficiency analysis for both developing and developed countries (Battese, 1992; Bravo-Ureta and Pinheiro, 1993; Ahmed et al., 2002; Ajibefun, 2002).

The following model is estimated using Frontier 4.1c program (Coelli, 1996):

$$\ln Y_i = \beta_o + \sum_{k=1}^{6} \beta_k \ln X_{ik} + V_i - U_i \qquad (3)$$

Where Y_i is the value of milk output for observation i in Ethiopian Birr ; X_1 quantity of roughage fed to cows in kg, X_2 quantity of concentrate fed to cows in kg, X_3 family labor man days, X_4 veterinary expense in Birr, X_5 breeding cost in Birr, X_6 value of hay purchased to fed the cows in Birr ; β_o is intercept and β_k is an $1xk$ vector of parameters to be estimated ; V_i is $iidN(0,\sigma_v^2)$ random stochastic disturbance term, independently distributed of the U_i; and U_i is a non-negative random variable associated with the technical inefficiency of production which is assumed to be independently distributed.

Step 2. Identifying Sources of Technical Inefficiency

The following multiple regression model was fitted for explaining technical inefficiency $(1-TE_i)$ for Cobb-Douglas stochastic frontier production function.

$$U_i = \beta_0 + \sum \alpha_i X_i + \varepsilon_j \qquad (4)$$

Where, U_i is technical inefficiency; X_i represents explanatory variables include: Age of the household head (years), farmers' experiences in farming (years), family size (no.), education i.e. years of schooling of the household head, farm size (ha), availability of credit (binary), access to extension services (categorical), availability of technical training opportunity on dairying (binary), off-farm income(binary), affiliation to farmers' group (binary) ; β_0 is the intercept; α_i are the unknown parameters to be estimated; and ε_j the unobservable random disturbance term.

The maximum-likelihood estimates for all the parameters of the stochastic frontier and inefficiency model, defined by Eqs. (3) and (4), are simultaneously obtained by using the program, FRONTIER Version 4.1c (see Coelli, 1996), which estimates the variance parameters in terms of the parameterization

$$\sigma_s^2 = \sigma_v^2 + \sigma_u^2 \; ; \qquad (5)$$

and

$$\gamma = \frac{\sigma_u^2}{\sigma_s^2} \text{ and } 0 \le \gamma \le 1 \qquad (6)$$

where the parameter γ must lie between 0 and 1.

The technical efficiency of production of the i^{th} farmer in the appropriate data set, given the level of his inputs, is defined in terms of the observed output by (Y_i^*) to the corresponding frontier output (Y_i), that is

$$TE_i = Y_i \; / Y_i^* = \exp(x_i\beta + V_i - U_i) / \exp(x_i\beta + V_i) = \exp(-U_i) \qquad (7)$$

Therefore, the technical efficiency of a farmer is between 0 and 1 $(0 \le TE \le 1)$ and is inversely related to the level of the technical inefficiency effect (Seyoum et al., 1998). The technical efficiencies can be predicted using the FRONTIER program which calculates the maximum-likelihood estimator of the predictor for Eq. (7) that is based on its conditional expectation (cf. Battese and Coelli, 1988).

4. RESULTS AND DISCUSSION

4.1. Innovation Systems and Networks Study

We perform a network analysis of innovation actors in the smallholder dairy production system. We examine the types of actors, the central players, the underlying collaborative relationships and its implication (how actors respond) and network differences between farmers groups and across geographic areas. The result is presented as follows.

4.1.1. The actors in the dairy production innovation system

We identified diverse actors in the system and their composition includes a range of public, private and civil society organizations. There were a total of 23 actors with a web of 179 ties (interconnections) taking part in the innovation systems network (Fig. 6). The density, which is an indicator for the level of connectedness of a network for the innovators network, is 0.70, i.e. 70% of all possible direct linkages are present. Furthermore, the degree centrality (cohesion) of the whole network is low (0.32), showing that only 32% of the connections are reciprocated. In other words, this indicates that those actors responsible for the exchange of technology and information supply, inputs and materials, credit and finance sources and marketing are not well connected. Therefore, this data tells us that there is a potential to increase the interconnections among actors in this network, which could contribute to improving the productivity of the dairy sector. In a relatively dense network (density close to one), an individual's network partners also communicate with each other, which implies that information may spread faster (Valente 1995). However, not all connections are important and needs to scrutinize connections based on their quality.

The study also showed that the smallholder dairy production innovation network has deficiency to incorporate other relevant service providers in the dairy AIS. Hence, Universities, breeding associations, private and NGO dairy advisory service providers and agro industries (agribusinesses) are missing in the system. Private sector actors including traders, brokers, and input supply small businesses and companies are very weak or non-existent (Figure 6).

A study by Altenburg *et al*. (2008) showed that innovative capacity within a given sector depends on the quality and density of interactive relationships between producers, enterprise (market) and support services. The latter include public and private organizations which carry out research, train, advice, finance, coordinate and regulate. It is, therefore, an innovative network should encompass all direct and indirect actors from the point of production up to the point of consumption of the dairy products either as recipients of support or as lending support and service to ensure program success. The direct actors are rural traditional smallholder producers, improved market oriented dairy farmers and dairy cooperatives and Unions, milk collectors, small scale dairy processors, dairy input suppliers, commercial dairy farms, commercial dairy processors, retailers, consumers. Indirect actors and support/service providers are government offices at all levels, dairy and livestock development projects, Non Governmental Organization, Producers associations, professional associations, financial institutions are among the list.

4.1.2. Role of public service providers in linkage facilitation

It was found that the public sectors play a central role in the dairy production innovation system. To determine which of the actors are more important (having a leading role), the analysis considered all the direct ties made by an actor (both originated and received) and the indirect ties (paths). The usual parameters of centrality were used to examine the centrality of the actors within the network in terms of: degree centrality (collaboration among actors), out-degree centrality (influence), in-degree centrality (prestige/prominence), closeness centrality (physical proximity) and betweenness centrality (liaison/most favoured position). Figure 4 provides the visual map of the central players and the underlying collaborative relationships and Table 9 presents the descriptive measures of the actors.

The analysis of Figure 6 and Table 9 reveals seven core institutions (service providers) that play a central role in smallholder innovation process. According to their order of degree centrality (collaboration), the institutions are: the District office of Agriculture *(*WoA), Integrated Livestock Development Project (ILDP), development agent (DA) at the *village* level, and the village administration (KA), cooperative promotion office (CPO), farmer development agent (FDA)[10], and Zonal office of Agriculture (ZOA). These are all public rural service providers that are closely linked with smallholder households and they typically operate around an interwoven network of agencies.

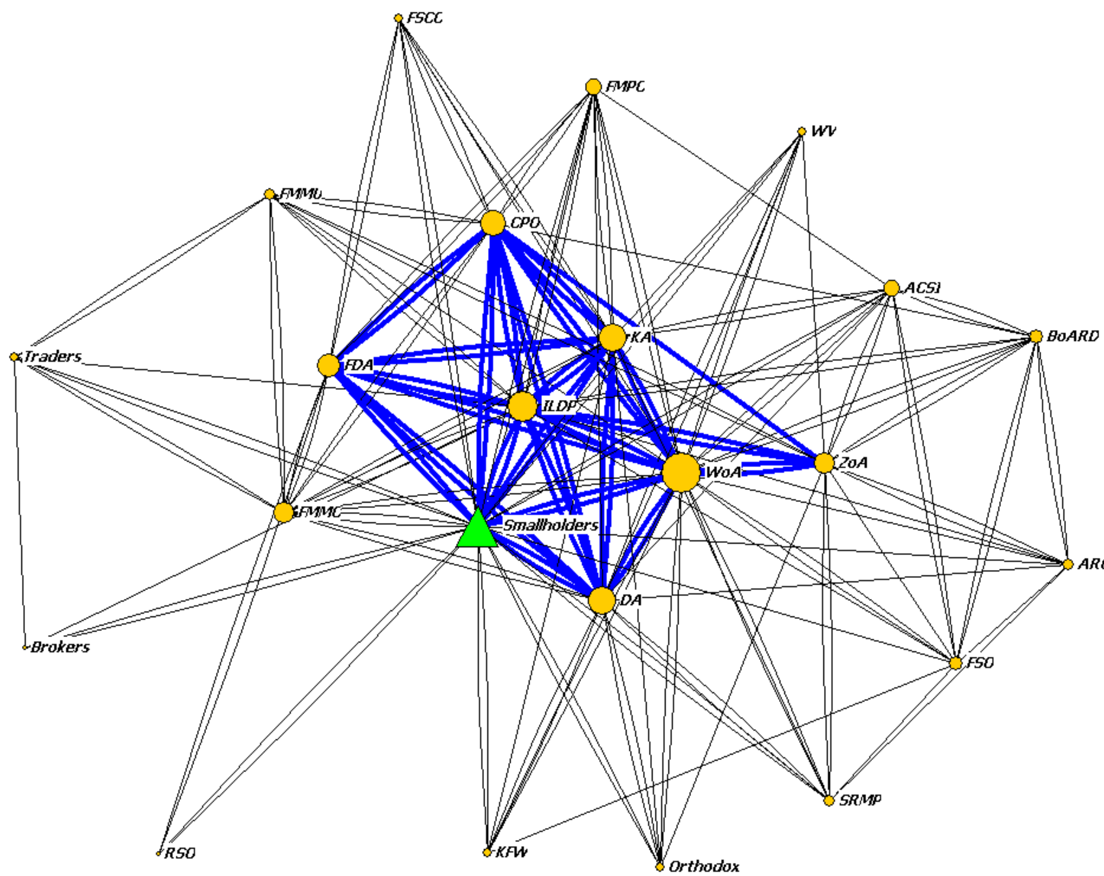

Figure 6. Innovators' Social Network and its Core Members
(Note: The size of each node is determined by the node's degree centrality. Please refer Table 4 for the abbreviations)

The results in Table 9 reveal that the WoA is the actor with the highest degree of centrality (0.79), i.e., it is the actor with more connections and hence can directly affect many of the actors. It is an actor with most influence (highest out-degree), most prominence (highest in-degree), highest closeness (is closest to the others) and highest betweenness (the actor with the most favoured position) because many other actors depend on it to make connections with other actors. This central position makes this actor more accessible to the smallholder dairy

[10]FDA (farmer development agent) is farmers used by ILDP as agent farmers to effectively demonstrate livestock technologies and to persuade others. According to their peers, farmers stated that skill and knowledge transfer has been more convincing, long lasting and cost effective.

farmers and results from its role in supplying knowledge/information, inputs, credit and market services. Therefore, WoA is supposed to be an intensely involved actor in innovation facilitation and can be considered as the most important channel for the diffusion of information and innovations (decision, technical support, procedure, etc.). Moreover, because its betweenness is high, it also serves as a liaison between different actors in the network.

Table 9. Measures of centrality of actors in the network

Actors	Degree	Out-Degree	In-Degree	Closeness	Betweenness
1 Smallholders	0.818	0.773	0.864	0.040	49.419
2District office of agriculture (WoA)	0.795	0.818	0.772	0.040	27.420
3 Integrated livestock development project (ILDP)	0.591	0.636	0.545	0.034	19.576
4 Development agent (DA)	0.568	0.500	0.636	0.033	9.554
5 Village Administration (KA)	0.545	0.455	0.636	0.033	9.987
6 Cooperative promotion office (CPO)	0.500	0.455	0.545	0.031	7.333
7 Farmer development agent (FDA)	0.455	0.455	0.455	0.029	5.971
8 Zonal office of agriculture (ZoA)	0.409	0.409	0.409	0.029	8.444
9 Farmers milk marketing cooperative (FMMC)	0.409	0.409	0.409	0.029	2.672
10 Farmer multi-purpose cooperative (FMPC)	0.318	0.364	0.273	0.028	0.468
11 Amhara credit & saving institute (ACSI)	0.318	0.318	0.318	0.028	2.250
12 Bureau of agriculture & rural development (BoARD)	0.295	0.318	0.273	0.026	0.801
13 Food security office (FSO)	0.273	0.272	0.273	0.029	3.173
14 Farmers milk marketing union (FMMU)	0.250	0.227	0.273	0.026	1.250
15 Sustainable resource management program (SRMP) – Bilateral Project	0.250	0.272	0.227	0.027	0.972
16 Agricultural research centre (ARC)	0.227	0.272	0.181	0.028	1.333
17 Farmers saving & credit cooperative (FSCC)	0.205	0.181	0.227	0.026	0.000
18 Traders	0.181	0.181	0.181	0.026	1.144
19 World Vision International (WV) - NGO	0.181	0.227	0.136	0.026	0.462
20 KFW - Bilateral Project	0.181	0.227	0.136	0.026	0.310
21 Orthodox (NGO)	0.181	0.227	0.136	0.026	0.462
22 Brokers	0.091	0.045	0.136	0.024	0.000
23 Religious social organization (RSO)	0.091	0.091	0.091	0.022	0.000

However, a high level of accessibility does not necessarily indicate good-quality service. The past 10 years performance assessment shows that the national Ministry of Agriculture and its branches at the region to district level couldn't perform client-oriented extension service (MoARD 2010), and its system is rather unresponsive to user demand (World Bank 2010). The country's extension service are said to be the largest worldwide in-terms of manpower, however, the service have generally failed to perform demand driven agricultural extension service to farmers (World Bank 2010). This implies that there are opportunities of improving the services of this actor. There are studies that indicate how agricultural extension needs to be re-oriented in Ethiopia (Habtemariam K. 2005; Berhanu *et al*. 2006; Beyerlee *et al*. 2007; World Bank 2006b and World Bank 2010).

Within the smallholder dairy production innovation network, other stakeholders that play central role is ILDP, which is responsible for providing various kinds of services (knowledge, input, credit and marketing). The high value of betweenness of ILDP (next to WoA) represents its strong potential to control interface relationships. ILDP, responsible for the overall project management and as a technical arm, represents the most central position between the local actors and other entities situated outside the district. In this case though, the project was crowding out other actors. As a result, farmers in the project area commented that, smallholder dairy farm production and productivity has not continued sustainably after the project terminated.

Similarly, ILDP used farmer development agents (FDAs), paravets, and community facilitators as a grassroots level extension agent with the assumption that the government development agents (DAs) were too overburdened to provide ILDP related extension services with the required intensity and quality. However, the capacity building effort of ILDP on these parallel structures was not used properly and stopped after the project terminated because of lack of coordination. In the context of definite time frames for development interventions, an important issue which was not well dealt with during the project period was how such innovative approaches can be institutionalized so that they can be sustained when development organizations leave. Moreover, ILDP was providing marketing extension services for livestock production. The unique nature of the extension service provided by ILDP was focused on activities, such as organizing farmers for collective marketing, providing market advice and market information, linking farmers with markets of both inputs and outputs etc. This experiences of the ILDP marketing extension can serve as a model for government extension service in the region as a whole, which does not consider marketing extension as an important component of the agricultural extension service.

Overall, the above result is consistent with the study on smallholder innovation networks in the Ethiopian crop sector by Spielman *et al*. (2010) which concludes that public extension and administration exert a strong influence over smallholder networks, potentially crowding out market based and civil society actors, and thus limiting beneficial innovation processes.

4.1.3. Role of public sector actors in marketing

While public sector actors are key providers of information, inputs and credit related, their role is by far less with respect to developing market linkages or transmitting marketing information (price) to small households. These actors have limited experience and capabilities with markets. The marketing actors which are dominantly private sector actors like the farmers' milk marketing cooperatives, farmers' multi-purpose cooperative, farmers' milk marketing union, traders, and brokers have a peripheral position (Fig. 6).

ILDP was opted for organizing farmers into specialized cooperatives to increase their bargaining power on input-output markets, to create financial capacity that producers as a group could have, and to increase their organizational capacity to pay for services (e.g. hiring professionals, to demand better services like extension, health, etc). However, this support was not kept on-going to make it sustainable by the current extension system.

Apart from milk marketing, cooperatives shall provide important services such as breed improvement, animal feed, veterinary and AI services for their members. Therefore, organizing the farmers into cooperatives may later evolve into creating breeder associations, for instance, like the Boran cattle breeders society in Kenya (BCBS 2010). To institutionalize animal breeding, there is a need to develop interest group of breeders' societies around the breed they are using to maintain their livelihoods. In addition, the dairy milk marketing cooperatives can potentially transform into business hubs, for instance, like the dairy business hub of Kenya (Mary *et al.* 2010) in which farmers could access services such as education, credit facilities, artificial insemination, extension services and inputs such as feed, transport and veterinary services. For this transformation to occur, the structure of dairy cooperatives must separate policy making roles (such as those left for the decision of cooperative members) from professional management (such as the day to day technical work). The transformation could be accelerated by organizing the cooperatives into business entities that are publicly owned with farmers holding equity.

4.1.4. Role of private sector actors

Despite the lack of isolated actors (Figure 6 and Table 9), some of the actors are not so extensively involved in relationships with all the actors but have a peripheral position within the social network. These are mostly private sector actors such as market traders (input supply small businesses), brokers, farmers' milk marketing cooperative/unions, are often peripheral to networks.

On the other hand, the development of a vibrant private sector, which is capable of providing the essential input and support services, is critically important to unleash the growth potential of the dairy production system in the area. In addition, private service providers are essential to accelerate rural economic growth, improve incomes and employment. There is a strong case for the extension service to allow and incentivize the entry and active participation of private sector actors. This implies that, in addition to the creation of enabling policies, laws and regulatory environment for private service delivery, public support for private service development is vital. This is because often market alone fails to allocate resources such as capital, skills and technological development to private sector and to ensure effective coordination with in a sector (Kurokawa *et al*. 2008)

4.1.5. The role of the civil society organizations

The civil society organizations have a relatively strong relationship with the public sectors. Mostly they are peripheral but have ties with other actors. These civil society organizations are mainly the non-governmental organizations (e.g. World Vision), community-based organizations (e.g. farmers' cooperatives) and bilateral projects. This is explained by the node degree (Fig. 7). In this case, it is possible to observe an attempt to become more integrated in the network. These actors are development partners to the WoA, and their work is often planned and implemented in consultation or collaboration with WoA. They have specific areas of expertise which they directly involve in actual activity implementation in specific areas or through training, technology delivery and financial support. Their comparative advantage lies in their ability to reach poor and marginalized people, and their operational flexibility and dynamism.

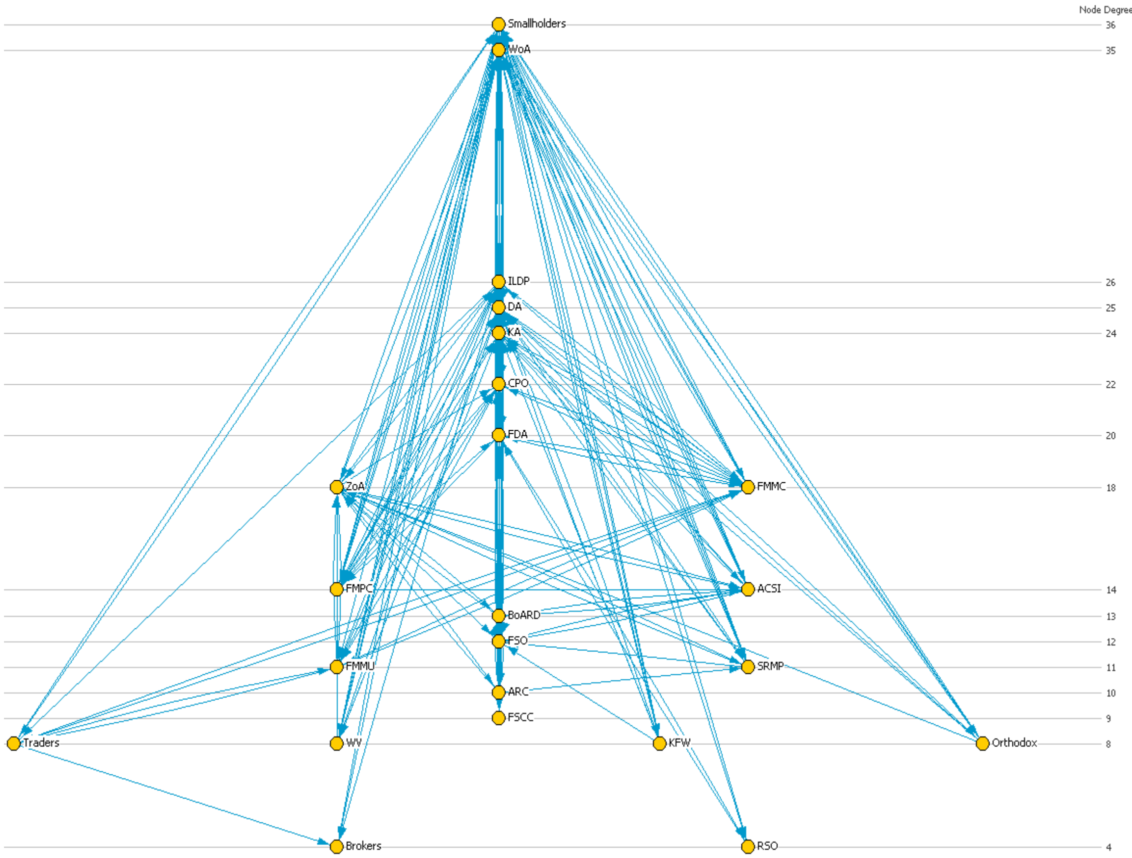

Figure 7. Innovators Network Node Degree
[Note: The size of each node is determined by the node's degree centrality. Please refer Table 4 for the abbreviations]

4.1.6. Differences between innovators and non innovators

Figure 6 and 8 provide a generalized overview of the typical networks for innovators and non innovators based on aggregated data from eight case study sites. Table 10 provides descriptive measures for both networks.

Table 10. **Descriptive measures of generalized networks**

Measure	Innovators	Non Innovators
Ego network size (no. of nodes)	22	18
Ego network density	0.70	0.86
Degree centrality	0.32	0.15
Closeness centrality	0.52	0.49

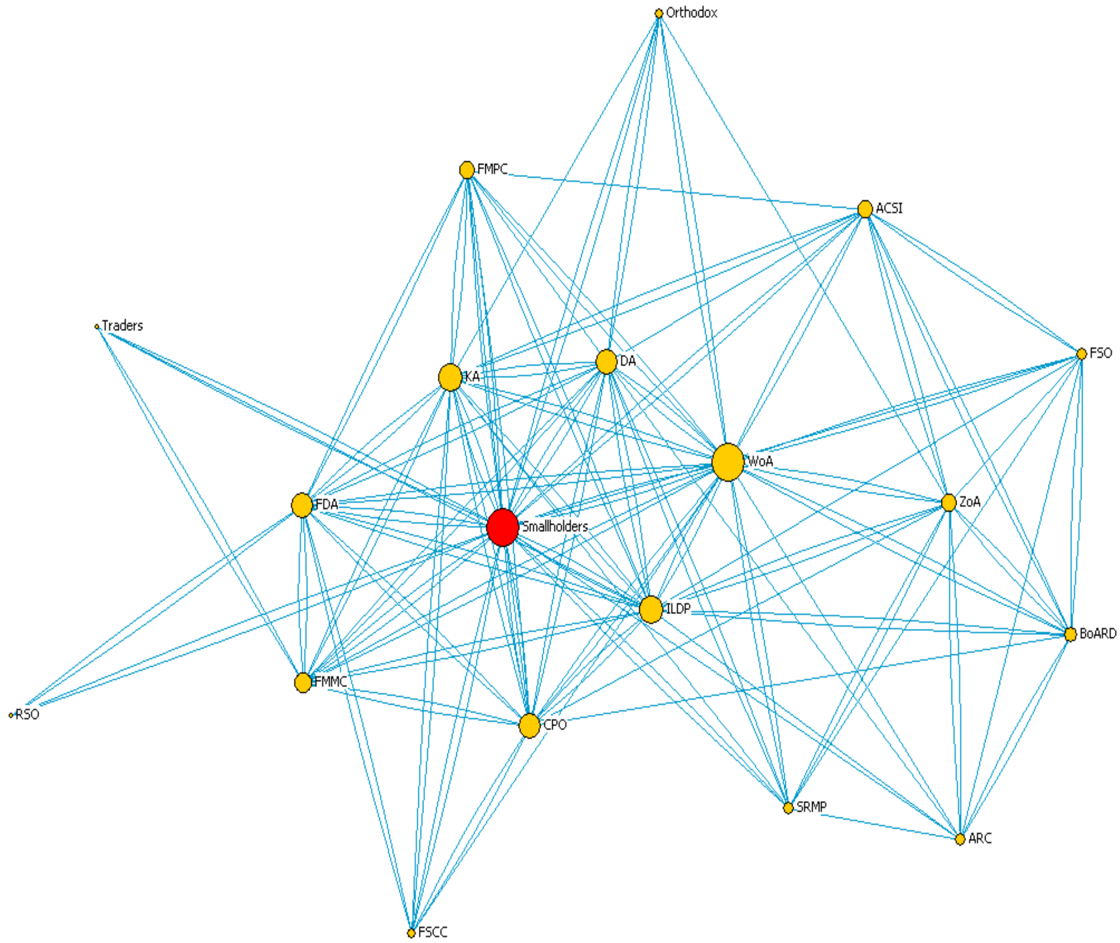

Figure 8. Generalised networks for Non-innovators
(Note: Figures are calculated for complete network except for ego network size]

We found that the types of actors are different in number. The innovators network exhibits 22 actors, whereas the non-innovators network has 18. In the latter network one bilateral development project actor, 2 NGOs and one marketing actor are missing.

Innovators are members of a larger network than non-innovators (explained by network size): implies that innovators have relatively greater access to formal and informal substitutes for knowledge/information, inputs, credit and markets than non-innovators who depend more on public service providers and quasi public institutions (Fig. 6, 8 and Table 10).

Innovators' network is less dense, denoting the presence of more actors than non innovators in the network; and innovators' networks are more centralised and closer, denoting greater proximity (shorter walks) to other actors (Table 10). This implies that innovators are associated with better access to sources of production knowledge, inputs, credits and markets and thus a potentially greater number of livelihood options and opportunities than non-innovators have. This finding can be further substantiated from illustrations in Table 3.

This finding has two implications to smallholder dairy innovation networks in the study area; that (1) Innovation networks vary within communities, (2) The diversity of connections helped to enhance innovation in the network. This has a widening consensus in other studies. Among the others, Scott states that actors who have more ties have greater opportunities because they have choices. This autonomy makes them less dependant on any specific other actors, and hence are more powerful (Scott 2000).

4.1.7. Organizational and institutional differences across the study regions / agro ecologies

The study revealed that, whereas the type and number of NGOs and bilateral development projects slightly varies from district to district, the organizations involved in supporting and or dissemination activities – the public service providers, quasi public and government supported farmers' cooperative actors are - similar across the 4 study areas.

On the other hand the study districts are different in agro-ecology, distance from the major dairy production systems, and other supporting structures such as input-output market, credit, infrastructure, etc. which requires locally relevant organizational, managerial and institutional arrangements. Distance and transportation costs are clearly relevant when talking about physical goods such as milk, which is perishable and bulky – the closer the service, the less the costs/charges of both service delivery and market transaction costs.

Many development studies such as Altenburg *et al.* (2008), Leeuwis (2004) and Pérez (1989) emphasises that development interventions to be successful, technological change should go hand in hand with institutional change. Ahmed *et al*. (2004), for example, showed that the rate of adoption of fodder and pasture land management technologies in Ethiopia was extremely low for several reasons, which include factors relating to institutions, economic incentives, support service delivery and policy.

In contrast to the above arguments, it is possible to suggest that there is a need to address the challenges of livestock production district by district. Considering the wide variation in capacity among districts, requires an innovation systems thinking. There is no 'one size fits all' solution to all problems. In this regard, the innovation systems framework offers insights on how to improve its capacity to innovate new locally relevant arrangements.

4.2. Impact of Social Networks on Dairy Adoption

This section presents results based on analysis of networks; which kinds of networks affect smallholder innovation and adoption decision; and how specific networks can enhance adoption of dairy production and thereby increases agricultural productivity and livelihood enhancement among smallholders. Results of probit estimations of modern dairy production adoption based on Equation (14) above are displayed in Tables 11 and 12. Table 11 reports the baseline estimation results with coefficients on the network variables and Table 12 reports the coefficients on all other characteristics. In all specifications (with the exception of Model 2), we control for village fixed effects. The chi-squared test statistic is significant at the 1% level, which implies the joint significance of the dairy adoption variables. Findings suggest the following:

Smallholders learn from their peers

Model 1 shows that peer networks have a positive and significant effect on the probability of modern dairy production adoption. The implication from this finding is that farmers who are members of a network can be more exposed to the innovation, and they can assess its suitability and learn from the experience of their network partners and adopt the dairy technology than those who are not members of a network. The estimated marginal effect of this variable indicates that at the 95% significance level, the probability of adopting the dairy technology increases by 3.8% for being a member in a peer network. Similar results were reported on the adoption of high yielding verities of rice and wheat during India's Green Revolution (Foster and Rosenzweig 1995; Munshi 2004) where the authors established that learning from ones own experience was significant. They also found that learning from neighbors mattered and led to increases in the profitability of farming operations. Also our findings concur with that of Matuschke et al. (2007) who perceived individual social networks matter to adoption by analyzing the impact of social networks on the adoption of hybrid wheat in India. Our findings are model consistent in such a way that larger peer networks that provide information on economic activities will create a robust influence on the adoption decision for technology that relates to a viable output. However, our findings contradict with

Bandiera and Rasul (2006), which argues that as more network members adopt a given crop or technology, the value of information that the smallholder gains from his or her own adoption process exceeds the value of information gained from the network (thus implying a negative coefficient on the square of the peer network effect).

Smallholders learn from providers of information other than their peers

As expected, non-peer (extension) network effects are significant at the 99% significance level and considerably larger in magnitude on dairy adoption (Model 1). The estimated marginal effect of this predictor indicates that the probability of adopting dairy technology increases by 43% for at least a one time visit by the extension service per year. This finding is model consistent given the fact that, the household has received extension advice from any source on dairying, and the supply-driven nature in which modern dairy production system have been introduced in the study area. On the other hand, unexpectedly the market networks are not a significant predictor of dairy adoption; supporting the finding that innovation is supply-driven by extension rather than market-driven by product demand articulated by traders and maybe due to the disaggregated structure of dairy input-output marketing systems in Ethiopia. Likewise, community networks have no direct effects, suggesting that community-based associations (for example, cooperatives, self-help groups, etc.) are less likely contribute to technology adoption decisions in this particular case. However, the role of these non-extension networks should not be undermined. Lessons from other countries, for example in India, shows that by using such market and community network alternative extension approaches they successfully increased average farm income by about 6% per year (against only 1% annual increase in the formal extension model), as well as creating rural employment due to the post-harvest handling of high-value products (see: Singh et al. 2006).

Both peer and non-peer networks remain significant and positive as in the baseline model

Model 2 exhibits that both peer and non-peer networks remain significant and positive as in the baseline model, although the magnitude of the reported marginal effects suggests that existence of a non-peer network (in fact, contact with extension) is significantly more influential on the probability of adoption with the complete estimation of equation 14 (full model). The estimated marginal effects of peer and extension networks for adoption of dairy technology are 3.7% and 35.5%, respectively.

Table 11. Dairy technology adoption estimated coefficients and marginal effects

Variable	Model 1		Model 2		Model 3	
	Coef.	Marginal effects	Coef.	Marginal effects	Coef.	Marginal effects
Constant	-2.4204 (0.3452)		-10.0790 (2.4635)		-7.9753 (2.2910)	
Peer network	0.1415 ** (0.0696)	0.0381 (0.0183)	0.1568* (0.0823)	0.0372 (0.0188)	0.0886 (0.0753)	0.0215 (0.0179)
Non-peer network (extension)	1.5536*** (0.1992)	0.4300 (0.0487)	1.4123*** (0.2053)	0.3553 (0.0544)	1.5271*** (0.2013)	0.3911 (0.0526)
Non-peer network (community)	0.0695 (0.0623)	0.0187 (0.0168)	0.0487 (0.0679)	0.0116 (0.0161)	0.0302 (0.0649)	0.0073 (0.0157)
Non-peer network (market)	0.0734 (0.0620)	(0.0197) (0.0168)	0.0270 (0.0670)	0.0064 (0.0160)	0.0446 (0.0653)	0.0108 (0.0159)
Log pseudo-likelihood	-124.80		-112.78		-115.26	
Village fixed effects	No		Yes		No	
Individual controls	No		Yes		Yes	
Observations	304		304		304	
Prob (Chisqd>value)	0.0000		0.0000		0.0000	
Pseudo R^2	0.2877		0.3563		0.3421	

Note: Dependent variable = 1 if household adopts modern dairy, 0 otherwise. Probit regression estimates with robust standard errors reported in parentheses. Coefficients are significantly different from 0 at the *90%, **95% and ***99% confidence level.

Few individual household characteristics matters for the adoption of dairy technology

Among the variables representing household characteristics, measures of education, female head household, non-land asset ownership and agro climatic condition (LGP) are found to significantly increase the smallholders' probability of dairy adoption (Model 2). As expected, farmers who are literate have greater ability to process information and search for technologies suitable to their production constraints than those who are illiterate. The estimated marginal effect of this variable indicates that at the 10% significance level, the probability of adopting the technology increases by 10.5% for being literate. Non-land asset ownership (livestock, production, housing, and other household assets), as well counter balance the cash shortage of farmers for investment can contribute positively to adoption; and also agro-climatic potential is associated to adoption and the magnitude of the marginal effect is 20.3% at 95% significance level. Similar results were reported from Mozambique (Bandiera and Rasul (2006), where the authors did a study on the impact of social networks by using a case study on sunflower seed adoption. Similarly, being a female headed household shows a positive effect on the probability of dairy adoption. This variable was modeled to have an inverse relationship to technology adoption but it found to be against the model assumption and turn out as positive may be due to a special support given to women headed farming households by all sources of the extension service.

Some household characteristics have no direct effect on dairy adoption

Among the variables representing household characteristics, credit access for example, is less likely related to adoption (Model 2). This is consistent with observations that, although dairying is a capital-intensive technology, there is no long-term credit availability for farmers by the public extension service and or other sources in the study area. Nevertheless, the assumption that credit positively associated to the likelihood of adoption is inline with a priori expectations and in concurrence with findings from a number of studies (Mariano et al., 2012). Similarly, neither age nor experience is significantly related to the probability of adoption, suggesting that experience constraints do not bind in this context. Old age happens to be one of the human capital characteristics that have been frequently associated with non-adoption in most adoption studies. At the time of the survey, the average age for both adopters and non-adopters were 48 years old (Table 3). In the same way, the effect of land asset on adoption is insignificantly associated maybe due to the inefficient use of the land resources. Whereas, land is a limiting factor in the study area expressed by high population density, optimal utilization of land in such situations is required. For example, in areas of high population density where farm size tends to be small, intensive systems give higher output and productivity per cow or per unit area.

Non-peer networks (specifically extension) remain significant and positive throughout the models

In the last set of the model variables, specifically the extension network shows significant and positive effect on dairy adoption with similar magnitudes as in previous estimation models. The estimated marginal effect of this variable indicates that the probability of adopting the technology increases by 39.1%. In addition, measures of education, female headed household, and non-land asset ownership are found to significantly increase the smallholders' probability of adoption with village fixed effects (agro-climatic, market access and village adoption rate) as control variables introduced in the previous models. The estimated marginal effects suggest that literacy, being female headed and asset ownership increases the likelihood of dairy adoption by 11.9%, 26.2% and 18.2%, respectively (Model 3).

Village fixed effects are suitable explanatory variables for peer network effect

Model 3 shows that the peer network is insignificant with the absence of village fixed effects as opposed to model 2, indicating that they maybe augment the impact of peer networks on adoption behavior. On the other hand aggregates of the individual characteristics may not have impact on peer-network effects. In contrast, model 3 shows that the peer network is insignificant with the presence of individual characteristics. This finding suggests that more social learning took place mainly not by individual characteristics but other adoption behaviors. Other studies show that social learning took place in homogeneous population (Munish 2004) and family and friends networks play a significant role in adoption decisions (Bandiera and Rasul 2006).

Table 12. Household and village fixed effect determinants of dairy adoption

Variable	Model 2		Model 3	
	Coef.	Marginal effects	Coef.	Marginal effects
Constant	-10.0791 (2.4635)		-7.9753 (2.2910)	
Age	0.0840 (0.0699)	0.0200 (0.0166)	0.0714 (0.0693)	0.0173 (0.0168)
Age ^{2}	-0.0949 (0.0666)	-0.0226 (0.0158)	-0.0801 (0.0658)	-0.0194 (0.0159)
Literacy (1/0)	0.5168 (0.2992) *	0.1045 (0.0506)	0.5908 (0.3048)*	0.1194 (0.0492)
Dependency ratio (%)	0.0085 (0.0063)	0.0020 (0.0014)	0.0073 (0.0060)	0.0018 (0.0014)
Female-headed household (1/0)	0.7676 (0.4108) *	0.2379 (0.1489)	0.8231 (0.4100)**	0.2618 (0.1513)
Land owned (ha)	0.1421 (0.1369)	0.0338 (0.0321)	0.1012 (0.1346)	0.0245 (0.0326)
Assets (ln)	0.8556 (0.3617)**	0.2033 (0.0861)	0.7463 (0.3503)**	0.1818 (0.0849)
Credit (ln)	-0.0764 (0.0635)	-0.0181 (0.0153)	-0.0582 (0.0629)	-0.0141 (0.0154)
Mean LGP (days)	0.0047 (0.0024) *	0.0011 (0.0006)		
Market access (1/0)	0.1342 (0.1291)	0.0319 (0.0301)		
Village adoption rate (%)	0.0033 (0.0156)	0.0008 (0.0037)		
Log pseudo-likelihood	-112.78		-115.26	
Village fixed effects	Yes		No	
Network controls	Yes		Yes	
Observations	304		304	
Prob (Chisqd>value)	0.0000		0.0000	
Pseudo R^2	0.3563		0.3421	

Note: Dependent variable = 1 if household adopts modern dairy, 0 otherwise. Probit regression estimates and marginal effects with robust standard errors reported in parentheses. *, ** denotes coefficients are significantly different from 0 at the 90% and 95% confidence level, respectively.

Overall, smallholder innovation is determined by different types of networks. Extension services, those provided by the Bureau of Agriculture (BoA), are major drivers of innovation in the case of dairy. Peer networks are likewise significant, but are of a much smaller magnitude. As expected, this is mainly because of the lack of any significant private companies or strong cooperatives etc. There is a very limited and sparse landscape of actors in the system and even those available are week and not well linked to the public extension service. For example, private companies, co-operatives, community-based organizations (traditional and informal organizations) and non-governmental organizations (NGOs) role are limited. However, in helping farmers diversify their farming system and adopt appropriate technologies requires an innovative extension intervention that incorporates alternative methods and approaches to extension. In considering alternative extension approaches and actors lessons from Asian countries (e.g. China, India, and Indonesia) illustrate how they transform their respective agricultural extension systems to become more comprehensive and innovative during periods of rapid economic growth (Swanson 2010).

4.3. Innovation and Technical Efficiency in Dairy Production

The maximum likelihood (ML) estimates of the parameters of the Cobb-Douglas stochastic frontier production function and the inefficiency model are presented in this section. The results are presented for: (1) pooled data; (2) dairy technology adopters and non-adopters; (3) men and women dairy farmers; and (4) variation across districts. First, we present the coefficients for the stochastic production function and then present the technical inefficiency coefficients and its determinants.

4.3.1. Pooled data

The stochastic production frontier estimation of smallholder dairy farmers

The results of the maximum likelihood estimates of the stochastic frontier production functions for dairy milk production are presented in Table 13. Findings reveal that coefficients of concentrate, labor and breeding are found to be positively significant to the dependant variable dairy milk output. The positive coefficient of concentrate, labor and breeding with respect to milk production implies that the higher the use of these inputs, the higher the total level of milk production.

From the nature of the Cobb-Douglas production function fitted, since the model is a log linear model, the coefficients represent elasticity of output with respect to the respective inputs. Production elasticities indicate the percentage change in output relative to a percentage change in input if other factors are held constant. Accordingly, the elasticity of milk output respect concentrate is 0.1078 meaning that 10% change in the total concentrate use will bring about 1.08 % change in the output of milk production if other factors are held constant. Labor has an elasticity of 0.4599 meaning that for 10% change in labor input; output of milk will change by 4.6 %. The same goes for breeding input with an elasticity of 0.1826 meaning that a 10% change in the expenditure on breeding will bring about a 1.83% change in the output of milk production in the study area.

Table 13. ML Estimates of the Cobb-Douglas Production Frontier and Inefficiency Models

Variable	Estimate	Standard error	t-statistics
Stochastic frontier production			
Constant	7.7526	0.4670	16.6016***
Roughage	-0.0445	0.0425	-1.0477
Concentrate	0.1078	0.0321	3.3558***
Labor	0.4599	0.2141	2.1483**
Health	0.0694	0.0546	1.2707
Breeding	0.1826	0.0646	2.8274***
Hay	-0.0041	0.0242	-0.1682
Inefficiency model			
Constant	-19.9794	42.9463	-0.4652
Household characteristics			
Age	-0.7184	1.4639	-0.4908
Age^2	0.9751	1.4815	0.6582
Family size	1.3106	1.2822	1.0221
Knowledge and Education Domain			
Education	-1.6999	1.6947	-1.0031
Business and Enterprise Domain			
Group membership	1.9282	7.8305	0.2462
Bridging Institutions Domain			
Extension	-0.4203	1.7345	-0.2423
Training	0.3434	4.6725	0.0735
Enabling Environment Domain			
Credit availability	1.1133	3.3495	0.3324
Off-farm income	-5.1824	7.4664	-0.6941
Farm size	-4.7861	5.1519	-0.9290
Variance parameters			
σ^2	136.0373	125.1240	1.0872
γ	0.9985	0.0014	736.9893***
Log likelihood function		-701.7271	
LR test (one-sided error)		153.0634***	

Note: *** significance at the 1% level; ** significance at the 5% level.

Inefficiency Model

The inefficiency effects described above were estimated against the components of the household characteristics and the local level innovation systems approach (Table 13). The result shows that all the selected variables in the model produced non-significant coefficients to the inefficiency model. The inefficiency model, although statistically not significant, age, education, farm size, extension visit and off-farm income opportunity are having negative sign as expected, indicating that these factors led to decrease in technical inefficiency or are important factors to increase production efficiency in the dairy production system. The coefficients in the inefficiency function are inefficiency effects and therefore a positive coefficient implies a negative effect on performance while a negative sign indicates a positive impact on efficiency.

Among the variables representing efficiency effects from the AIS framework in Table 13, measures of education in the knowledge and education domain shows the expected effects in reducing inefficiency. The role of education in technology adoption has been extensively documented. Schooling has been shown to provide substantial externality benefits by increasing farm output and shifting the production frontier outwards (Wier and Knight, 2005; Seyoum et al., 1998; Asres et al., 2012). In the business and enterprise domain, group membership of the household head is found to be non-significant and negatively related with dairy production efficiency despite our expectation that it increases dairy production efficiency by facilitating input output marketing. This could partly be due to innovation is supply-driven by extension rather than market-driven by product demand and also may be due to the disaggregated structure of dairy input-output marketing systems in Ethiopia. Extension from the bridging institutions domain is not significant, but it had the expected sign which indicates that the involvement of extension agents to visit dairy farmers tends to reduce the technical inefficiency of milk production. In the enabling institutions domain, off-farm income and farm size are not significant, but they had the expected signs which indicate both variables had positive contribution to dairy production efficiency.

The significant gamma (γ) statistic, which is a measure of the overall, of 0.9985 indicates that about 99.85 % variation in the output of milk production would be attributed to technical inefficiency effects (those under farmer's control) alone while only 0.0015% would be due to random effects i.e. beyond the farmers control (Table 13). The high value of parameter γ highlights the importance of inefficiency effects in explaining the total variance in the model.

The level of technical efficiency is predicted simultaneously with the estimated production function and it was found that the mean technical efficiency is about 26 percent (Table 4). Thus in the short run, there is a scope for increasing dairy milk production by about 74 % using the same level of inputs, but improved management and resource reallocation. One of such measures is addressing, the issue of negative elasticity of dairy feed (roughage and hay), other non-significant input (veterinary service) and improving the innovation capacity of the local level agricultural innovation system actors. The cumulative and frequency distribution of dairy farmers efficiency scores are presented in Table 14. Above average (>50%) efficiency for 19.4 percent of the farmers in dairy production could be the result of ILDP implemented in the study area to reduce poverty and support the enhancement of service delivery. Those activities could have a long-term impact that could have spillover effects to other non-project farmers.

Table 14. Frequency distribution and deciles range of TE estimates of Dairy farmers

Efficiency level	frequency	Percent
0.80-0.89	4	1.3
0.70-0.79	21	6.9
0.60-0.69	13	4.6
0.50-0.59	20	6.6
< 50	246	80.6
Total	304	100
Mean efficiency	0.2617	
Minimum	0.02	
Maximum	0.85	

4.3.2. Technical efficiency of dairy technology adopters and non-adopter farmers

The stochastic production frontier estimation

The stochastic production frontier model estimates and those for the technical inefficiency model for adopters and non-adopter farm households are presented in Table 15.

In the model, a coefficient of breeding is found to be positively significant to the dependant variable dairy milk output to both groups. The coefficient of health and breeding are found to be significantly positive in case of adopters. Similarly, the coefficients of concentrate, labor and breeding are significantly positive in case of non-adopter farmers. The negatively non-significant coefficient of roughage and positive but non significant coefficient of hay inputs in both groups imply no effect to the output.

The output elasticities of inputs for both adopters and non-adopter farmers are variable. For the adopters group, output elasticity of inputs was highest for breeding (0.1798), followed by health input (0.1105). In the non-adopters group, output elasticity of inputs was highest for labor (0.5706), followed by breeding (0.1790), and concentrate (0.1186). The overall results indicate that four inputs, concentrate, labor, health and breeding have a major influence on milk output of both adopters and non-adopter farmers.

Inefficiency Model

In the inefficiency model (Table 15), although statistically not significant, age, farming experience (age^2), family size, education, farm size, credit, technical training, and off-farm income are negative indicating important factors to increase production efficiency in one or the other groups.

Table 15. Maximum-likelihood estimates for parameters of the Cobb-Douglas stochastic frontier production functions for dairy technology adopter and non-adopter farmers

Variable	Adopters		Non-adopters	
Stochastic frontier	Coefficient	Std.dev	Coefficient	Std.dev
Constant	8.4665	0.0696	7.0735	0.6692
Ln roughage (kg)	-0.0296	0.0402	-0.0012	0.0598
Ln Concentrate (kg)	0.0470	0.0613	0.1186***	0.0457
Ln labor (man days)	0.2094	0.3088	0.5706***	0.3046
Ln health expense(Birr)	0.1105***	0.0437	0.0316	0.0843
Ln breeding expense(Birr	0.1798***	0.1741	0.1790**	0.1013
Ln hay purchase(Birr)	0.0072	0.0509	0.0054	0.0400
Inefficiency model				
Constant	0.1528	0.9992	-20.5590	29.29
Age	0.1548	0.2274	-0.5387	0.9774
Age^2	-0.0996	0.2354	0.6632	0.9295
Family size (number)	-0.7839	0.7971	1.8860*	1.2468
Education (years)	-1.2337***	0.4255	-0.2010	0.4045
Farm size (ha)	1.1279	0.9694	-3.4067	2.7478
Credit availability (1/0)	-2.1958**	1.1189	2.7738	3.2894
Extension (number)	0.3813	0.8949	0.1217	1.3739
Training (1/0)	-0.9522	1.0179	3.0090	3.3153
Off-farm income (1/0)	- 3.3906***	1.2709	1.0874	4.2103
Group membership (1/0)	1.2093	1.0353	3.8079	5.2752
Variance parameters				
σ^2	17.2752***	0.9451	78.1963*	53.3134
γ	0.9999***	0.0000	0.9958***	0.0031
Log likelihood function		-146.93		-531.73
LR test (one-sided error)		85.87***		88.96***

Note: The coefficients in the inefficiency function are inefficiency effects and therefore a positive coefficient implies a negative effect on performance while a negative sign indicates a positive impact on efficiency. Significant at * 10%, **5%, ***1%.

The bridging institutions domain (Extension visit) and business and enterprise domain (group membership) proxies do not seem to be important factors affecting farm household efficiency in both groups. The explanation to this could be, extension in Ethiopia has a supply driven nature and its quality is very low and group memberships have no direct effect and are less likely contribute to technology adoption decisions (Asres et al., 2012).

Knowledge and education domain (Education) and among the enabling environment domain (credit access and off-farm income opportunity) variables are positive and significant factors affecting farm household efficiency in the adopters group. The role of education in technology adoption has been extensively documented. Credit and off-farm access also contributes to farmer adoption of new technologies and practices by easing farmers' liquidity constraints.

Unlike the adopters group, the positive but statistically significant coefficient for family size variable in the non-adopters group indicating possible excessive use of man power which is a problem of allocative efficiency. The negative sign on age shows that younger head of households are productive in the non-adopters group and hence important factor to increase production efficiency.

The parameter σ^2 and γ results show significant at 1% level for both groups (except for non-adopters group σ^2 that was significant at 10%). The significance value of the σ^2 shows the presence of inefficiency effects in dairy milk production in the study area while the significant γ of 0.9999 and 0.9958 indicates that about 99.99% and 99.58% variation in the output of the dairy milk production would be attributed to random effects, for adopters and non-adopter farmers, respectively.

Table 16. Technical efficiency frequency distribution and deciles range of dairy farmers by adoption status

Deciles range of TE	Adopters (N=80)		Non-adopters (N=224)	
	Frequency	%	Frequency	%
0.80-0.89		1.2		0.9
0.70-0.79		17.5		3.1
0.60-0.69		7.5		3.1
0.50-0.59		13.8		5.0
≤50		60		87.9
Total		100		100
Mean TE	0.40		0.21	
Std.dev.	0.25		0.20	
Minimum	0.03		0.02	
Maximum	0.85		0.85	

The mean predicted technical efficiency for farmers within the adopters group was estimated to be 0.40 with 0.25 standard deviations, while for non-adopter farmers, the mean technical efficiency was 0.21 (Table 16). The fact that both groups have technical efficiency levels below 50%, suggests a relatively very low level of innovation capacity in the dairy production system which resulted substantial technical inefficiency in dairy production operations in both adopters and non-adopter farmers given the available technologies.

4.3.3. Technical efficiency of men and women dairy farmers

Disaggregating the dairy production data by gender shows that women headed households were more technically efficient than male headed households in the study area. This could be due to the fact that women spend substantial amounts of time doing livestock activity (FAO, 2011). This is denoted in Table 17 with an efficiency score for the women farmers of 43.89% compared to 23.54% for men farmers.

4.3.4. Technical efficiency of dairy farmers across districts

It is also possible to infer something about the general status of TE in each district. For example, Table 17 shows the predicted TE values. Values vary from 20.6% in Debark to 30.9% in Wogera district. Districts relatively with higher technical efficiencies above the overall average are those progressing with breeding, education, access to off-farm income opportunity and group membership.

Table 17. Summary of farm efficiency descriptive statistics

Variable	Mean	StD	Min	Max
Efficiency combined	0.2617	0.2280	0.02	0.85
Efficiency adopters	0.4000	0.2481	0.03	0.85
Efficiency non-adopters	0.2124	0.1987	0.02	0.85
Efficiency men	0.2354	0.2274	0.02	0.85
Efficiency women	0.4389	0.3757	0.03	0.85
Efficiency by District - Gonderzuria	0.2190		0.03	0.85
- Lay armachiho	0.2904		0.02	0.85
- Wogera	0.3092		0.02	0.85
- Debark	0.2061		0.02	0.77

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

This study presents evidence based on local-level analysis of the smallholder dairy production innovation system; how innovation systems and networks influences smallholder innovation processes; how social networks contribute to the efforts to increase productivity through adoption of dairy technologies; and how different components of the local-level agricultural innovation system increase technical efficiency and thereby boost productivity and commercialization among smallholders.

Summary of the findings from the three interrelated studies suggest that the potential of innovation system is not yet being fully realised. Innovations tend to follow a linear path of supply-driven technology dissemination through the public sector. Public service providers are the dominant source of information and resources in smallholder dairy innovation networks despite the quality of their service is weak. The potential contributions of other innovation systems actors – private sector service providers, NGO's, civil society, and so on – often remain untapped. Hence, further development of the dairy innovation systems is critical to the creation of a more commercialized dairy sector where dynamic and responsive networks are effective in responding to dairy production and productivity at household, regional and national level.

To illustrate this argument, this study examines the role of different types of networks on adoption decision and technical efficiency of smallholder dairy farmers. Farmers acquire knowledge about improved dairy practices mainly from the public extension system, and to a lesser extent through their close associates (peer networks – family, friends and neighbors who serve as sources of economic advice). Other non-peer networks such as community and market networks are not found to be determinant actors in the adoption of dairy production technology. Although these non- extension actors are important to serve purposes of information and knowledge sharing as alternative channels, they are proving to be not effective. This happens because of their organizational weaknesses due to a lack of system wide approach to promote human capital development and social capital formation at the local level.

Agricultural extension being a public-good in Ethiopia, the public extension services crowd other peer and non-peer network sources of information and is being the leading source of information and resources in smallholder innovation networks. This suggests that the potential contributions of other social networks—peer network, community network and market networks that can significantly affect adoption are not properly managed to promote productivity. Similarly, the technical efficiency study prove that the overall mean efficiency score among dairy farmers is very low (26%) and farmers are yet far from reaching the production frontier, suggesting that there is room for significant increase of production by reallocation of the existing resources and by enhancing innovation capacity of different actors.

Given the need for greater innovativeness in the dairy sector to enhance productivity, increase production, and improving the incomes of small-scale households, these findings suggest several points for further consideration. We recommend for policies and programs:

(1) To reform the current agricultural extension system to address institutional and policy issues that constrains effective agricultural innovation system. To promote innovation the public sector could further support interactions, collective actions, and broader public private partnership programs. The public sector might be better suited to a bridging or facilitative role, knowledge broker and matchmaker between smallholders and other service providers and support agencies, rather than taking a role that can potentially crowd other innovation system actors. Among others, the agricultural extension service which is one of the major actors, its comparative advantage lies in its transformation as a bridging organization, linking the different bits of knowledge held by different actors, and facilitates its application and use, thereby leading to innovation;

(2) Given the adoption of dairy production technologies as an essential means of boosting productivity, there is an immediate need to focus on the innovative use of all kinds of social networks, and therefore to design suitable strategies that leverage social networks to complement the current extension approaches.

(3) Different components of the local-level agricultural innovation system have to interact to improve the innovation capacity of different actors and thereby improve technology adoption and the technical inefficiencies. There is a need for policies, programs, and practices to (a) include a wide range of new actors particularly the private sector actors; (b) as part of the government efforts in the dairy sector should include building the capacity of the private service providers, including credit mechanisms and stimulate demand for their services; (c)

considering capacity constraints (financial and technical), partnership with development partners including NGOs may be useful to enhance program implementation. However, this will require strong collaboration and coordination at all levels – coordination which must be institutionalized prior to the roll-out that can avoid parallel structures and capacitate the existing government structures; (d) strengthen the capabilities of smallholder farmers to take advantage of realistic and remunerative opportunities through access to knowledge, credit, and markets. To do that though, if we are to go to high value products like dairy, then farmers have to be organized in groups particularly the smallholder households. Building their social capital becomes very crucial in such a way that helping men and women farmers organize into producer and self help groups to increase market access and other needed services. Once farmers get organized into groups they can operate at economies of scale and reduce transaction costs. (e) The habits and practices (institutions) that have conventionally shaped extension as a technology dissemination agency have to change significantly, if extension has to play the wider role.

Limitations and Future Research

We note that the present study is based on data from a specific locality, a follow-up is recommended to examine national level AIS in the Ethiopian dairy sector. This would help policy makers in strengthening the capacity of and investing more in innovation systems.

This study also explores new inroads for the understanding of local-level innovation processes, emphasizing in particular the role of social networks, complementing the conventional approaches and opens a wide door for further study on the role of different networks on adoption and technical efficiency and thereby improving productivity of the livestock sector both at local and national level.

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APPENDIX

Appendix 1. Innovators Network Data

Actors	ILDP	DA	FDA	WoA	CPO	KA	ZoA	FSO	ACSI	FSCC	FMPC	FMMC	FMMU	WV	KFW	SRMP	Orthodo1	Traders	Brokers	RSO	BoARD	ARC	Smallholders
ILDP		1	1	1	1	1	1	0	0	0	1	1	1	0	0	0	0	1	1	0	1	1	1
DA	1		1	1	1	1	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	1
FDA	1	1		1	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0	1	0	0	1
WoA	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	1
CPO	1	1	1	1		1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	1
KA	1	1	1	1	1		0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1
ZoA	1	0	0	1	1	0		1	1	0	0	0	1	0	0	1	0	0	0	0	1	1	0
FSO	1	0	0	1	0	0	0		1	0	0	0	0	0	0	0	0	0	0	0	1	1	1
ACSI	0	1	0	1	0	1	1	1		0	0	0	0	0	0	0	0	0	0	0	1	0	1
FSCC	0	0	1	0	1	1	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	1
FMPC	1	1	1	1	1	1	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0	1
FMMC	1	1	1	1	1	1	0	0	0	0	0		1	0	0	0	0	1	0	0	0	0	1
FMMU	1	0	0	0	1	0	1	0	0	0	0	1		0	0	0	0	1	0	0	0	0	0
WV (NGO -I)	0	1	0	1	0	1	1	0	0	0	0	0	0		0	0	0	0	0	0	0	0	1
KFW(NGO-I)	0	1	0	1	0	1	0	1	0	0	0	0	0	0		0	0	0	0	0	0	0	1
SRMP(NGO-I)	0	1	0	1	0	1	1	1	0	0	0	0	0	0	0		0	0	0	0	0	0	1
Ortho(NGO-L)	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0		0	0	0	0	0	1
Traders	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0		1	0	0	0	1
Brokers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	1
RSO	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	1
BoARD	1	0	0	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0		1	0
ARC	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1		1
Smallholders	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	1	1	1	1	1	0	0	

Source: Own Survey 2010 / 11

Appendix 2. Non Innovators Network Data

Actors	ILDP	DA	FDA	WoA	CPO	KA	ZoA	FSO	ACSI	FSCC	FMPC	FMMC	SRMP	Orthod	Traders	RSO	BoARD	ARC	Smallholders
ILDP		1	1	1	1	1	1	0	0	0	1	1	0	0	1	0	1	1	1
DA	1		1	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	1
FDA	1	1		1	1	1	0	0	0	1	1	1	0	0	0	1	0	0	1
WoA	1	1	1		1	1	1	1	1	1	1	1	1	1	0	0	1	0	1
CPO	1	1	1	1		1	0	0	0	1	1	1	0	0	0	0	0	0	1
KA	1	1	1	1	1		0	0	1	1	1	1	0	0	0	0	0	0	1
ZoA	1	0	0	1	1	0		1	1	0	0	0	1	0	0	0	1	1	0
FSO	1	0	0	1	0	0	0		1	0	0	0	0	0	0	0	1	1	1
ACSI	0	1	0	1	0	1	1	1		0	0	0	0	0	0	0	1	0	1
FS&CC	0	0	1	0	1	1	0	0	0		0	0	0	0	0	0	0	0	1
FMPC	1	1	1	1	1	1	0	0	1	0		0	0	0	0	0	0	0	1
FMMC	1	1	1	1	1	1	0	0	0	0	0		0	0	1	0	0	0	1
SRMP	0	1	0	1	0	1	1	1	0	0	0	0		0	0	0	0	0	1
Orthod	0	1	0	1	0	1	1	0	0	0	0	0	0		0	0	0	0	1
Traders	0	0	0	0	0	0	0	0	0	0	0	1	0	0		0	0	0	1
RSO	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0		0	0	1
BoARD	1	0	0	1	1	0	1	1	1	0	0	0	0	0	0	0		1	0
ARC	0	1	0	1	0	0	1	0	0	0	0	0	1	0	0	0	1		1
Smallholders	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	

Source: Own Survey 2010/11.