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Understanding factors affecting technology adoption in smallholder livestock production systems in Ethiopia

The role of farm resources and the enabling environment

Kebebe Ergano Gunte

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Understanding factors affecting technology adoption in smallholder livestock production systems in Ethiopia

The role of farm resources and the enabling environment

Kebebe Ergano Gunte

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Abstract

In response to population growth, rising income and urbanisation, the demand for livestock products, such as milk, meat and eggs is growing in Ethiopia. The growing demand for milk products offers opportunities for smallholders to realize better livelihoods. Whereas the growing demand for milk products in Ethiopia is widely recognised, the dairy sector has not been able to produce adequate milk to satisfy this demand, mainly due to low productivity of dairy animals. The use of technological inputs, such as improved breeds of dairy cows and cultivation of improved forages, is often seen as a prerequisite to increasing livestock productivity and resource use efficiency in the smallholder dairy sector. However, adoption of such technologies has been low, despite numerous efforts to disseminate the technologies in the past. This poses a question as to why the majority of smallholders have not adopted livestock technologies in the Ethiopian highlands. The overall objective of this study was understanding the factors affecting adoption of technologies that enhance the productivity of livestock production and water use efficiency in the Ethiopian highlands, with particular emphasis on dairy production. The study was intended to deepen the understanding on the role of factors at the levels of farm households, value chains and macroeconomic institutions and policies on farmers' decision to adopt technologies. The study employed interdisciplinary approach to analyse micro and macro level constraints that affect adoption of technologies in livestock production. The findings in the empirical chapters show that low adoption of the technologies that enhance the productivity of livestock production and water use efficiency stem from farmers' limited access to farm resources, differentials in potential welfare impacts of the technologies, lack of effective and reliable supply chains for inputs and outputs, inadequate physical infrastructure and weak institutions and policies. The findings show that smallholders have been subjected to multiple constraints. Given the multiple constraints at different scales and the associated transaction costs facing smallholders in rural Ethiopia, the returns to investment for the technologies may be too low to justify widespread adoption of the technologies. Therefore, adoption of technologies in the dairy sector requires interventions at production, storage, transportation, processing and marketing chains and at macroeconomic institutions and policies. In the short and medium term, dairy development programs in Ethiopia will have a better chance of success if they target farmers who have better resource endowments and

who are connected to better-functioning value chains rather than blanket technology scaling-up strategies targeting the majority of smallholders. Future agricultural research needs to shift the focus from predominantly developing new biophysical technologies towards social science research that assesses issues at value chain, macroeconomic institutions and policies that influence adoption of technology.

Contents

Chapter 1
General Introduction 1

Chapter 2
Strategies for improving water use efficiency of livestock production in rain-fed systems 15

Chapter 3
Characterisation of adopters and non-adopters of dairy technologies in Ethiopia and Kenya 37

Chapter 4
Impact of dairy technology adoption on household nutrition and income in Ethiopian highlands 61

Chapter 5
Understanding socio-economic and policy constraints to dairy development in Ethiopia through innovation systems function analysis 89

Chapter 6
General Discussion 119

Summary 137

Samenvatting 141

Acknowledgements 145

About the author 147

List of publications 149

Education certificate 151

Colophon 152

Chapter 1

General Introduction

1.1. Background

In response to population growth, rising income and urbanisation, the demand for livestock products, such as milk, meat and eggs is growing in Ethiopia (Delgado, 2003; Smith, 2013). The growing demand for milk products offers opportunities for smallholders to realize better livelihoods. Dairy farming is often considered as a promising option to improve household income and nutrition in developing countries (Francesconi et al., 2010; Headey et al., 2014). Whereas the growing demand for milk products in Ethiopia is widely recognised, the dairy sector has not been able to produce adequate milk to satisfy this demand, mainly due to low productivity of dairy animals. The national average daily milk yield from indigenous dairy cows is 1.9 litres per cow (Tegegne et al., 2013), whereas the average daily milk yield was 2.3 litres per cow in the Ethiopian highlands. Despite the large cattle population and the favourable environment for dairy in the Ethiopian highlands, Ethiopia is a net importer of dairy products. Furthermore, the country's livestock sector is increasingly challenged by limited availability of land and water resources, and climate change (Godfray et al., 2010; Smith, 2013). Especially in the Ethiopian highlands, where this study was conducted, agricultural systems are mainly rain-fed and highly vulnerable to rainfall variability (Alemayehu et al., 2012). The low and uneven distribution of rainfall leads to water shortages for food and feed production. Hence, increasing productivity and water use efficiency of livestock production have become important development issue in Ethiopia (Descheemaeker et al., 2010; Haileslassie et al., 2009; Peden et al., 2009).

Sustainable intensification has been advocated as a pathway to enhance agricultural productivity and to increase resource use efficiency in developing countries (McDermott et al., 2010; Smith, 2013). Sustainable intensification is generally defined as producing more output from existing resources while minimizing pressure on the environment (Ali and Talukder, 2008; Pretty et al., 2011). Sustainable intensification of livestock production involves, among others, the use of technologies in breeding (e.g., crossbreeding using artificial insemination and genomic selection), in feeding (e.g., planting multipurpose fodder trees and use of agro-industrial by-products) and in animal healthcare (e.g., vaccination and anti-parasitic medicaments). Implementation of these technologies would allow a higher milk yield from limited land and water resources. In fact, adoption of technologies that increase agricultural productivity and promote environmental sustainability remains crucial to achieving the goals of food security and poverty alleviation in Ethiopia. Following introduction of the first batch of exotic breeds of dairy cattle in the early 1950's, improved technologies in animal breeding, feeding and animal healthcare have been promoted to transform subsistence dairy production into a market-oriented dairy enterprise in Ethiopia (Ayele et al., 2012; Duncan et al., 2013; Holloway et al., 2000; Mekoya et al., 2008; Oosting et al., 2011).

Furthermore, increasing the efficiency of water used for livestock feed production could reduce future demands for agricultural water. Peden *et al.* (2007) defined livestock water productivity (LWP) as the ratio of beneficial livestock outputs and services to actual evapotranspiration of water in the production of livestock feeds. In mixed crop-livestock systems, LWP is a measure of the ability of the livestock production system to convert available rainwater into beneficial livestock outputs and services. More recently, researchers have suggested technical interventions, such as improved rainwater management, better grazing land management practices, and technologies could improve livestock water productivity in the Ethiopian highlands (Amede et al., 2009; Descheemaeker et al., 2010; Peden et al., 2009). These technological interventions have the potential to improve water use efficiency in feed production and to increase feed utilization efficiency of the animals. While there have been a few cases of success, the technologies have not been widely implemented by smallholders and the productivity of dairy cows remains low, despite numerous previous attempts to disseminate the technologies (Ayele et al., 2012; Duncan et al., 2013). The question arises as to why smallholders have not adopted agricultural technologies and taken advantage of productivity gains in Ethiopia. Hence, understanding the factors affecting technology adoption is an important area of enquiry.

There is a considerable body of literature which deals with smallholders' agricultural technology adoption in developing countries (Franzel et al., 2001; Gebremedhin et al., 2003; Place et al., 2009; Staal et al., 2002; Tefera et al., 2014). Agricultural household models have been used as a standard framework for technology adoption studies in developing countries (Adesina and Baidu-Forson, 1995; De Janvry et al., 1991; Shiferaw and Holden, 1998). Agricultural household models postulate that a household's decision to use agricultural technologies is influenced by its ownership of physical assets and human resources. Agricultural household models explore the decision of smallholders to adopt technologies based on micro-level factors, such as farm characteristics, household socioeconomic characteristics and access to input and output markets (Abdulai and Huffman, 2005; Franzel, 1999; Staal et al., 2002). So far, adoption studies, framed in agricultural household models, have made considerable contribution to the understanding of the factors influencing technology adoption by smallholders. Literature shows that availability of household labour, household's education attainment, better endowment of physical assets, availability of own financial capital and access to information facilitate adoption of agricultural technologies (Feder et al., 1985; Kassie et al., 2015; Knowler and Bradshaw, 2007; Larson and Gurara, 2013; Le et al., 2012). Moreover, the potential impacts of technologies on household welfare outcomes, such as household nutrition and income, may differ between different groups of farmers (Udo et al., 2011). Hence, the difference in expected impacts of technology adoption on welfare outcomes could be one of the reasons for low technology adoption (Fischer and Qaim, 2012; Suri, 2011). The question whether adopters and non-adopters of technologies inherently differ in welfare outcome potentials, however, has been hardly addressed.

Other sets of studies have used agricultural household models to analyse the role of constraints at the value chain level, such as transport infrastructure, the functioning of the agricultural market for the supply of inputs and services to the farmers, and buying and distribution of outputs from rural areas on technology adoption (Barrett, 2005; Fafchamps, 2004; Jayne et al., 2010; Kijima et al., 2013; Poulton et al., 2006). Dairy cooperatives and dairy hub models, for example, are two organizational forms that have been tried in Ethiopia to overcome marketing constraints at the value chain level (Bernard and Spielman, 2009; Jaleta et al., 2013). Although agricultural household models provide a good starting point for thinking about technology adoption by smallholders, they also have limitations.

In recent decades, agricultural development researchers have cast doubt on the adequacy of predicting household's decision to adopt technologies based on micro-level factors and a few constraints in the value chain (Birner and Resnick, 2010; Maertens and Barrett, 2013). Some researchers have argued that macroeconomic institutions and policies explain more of the variation in adoption of technology by smallholders than the biophysical, farm and household socioeconomic characteristics do (Birner and Resnick, 2010; Dillon and Barrett, 2014; Sheahan and Barrett, 2014). Institutional and policy issues at the level of value chains and policy context may not be sufficiently addressed by agricultural household models in ways that help formulation of interventions to overcome current barriers to technology access and adoption (Barrett et al., 2010; Hounkonnou et al., 2012; Klerkx et al., 2010). Institution is defined as formal and informal rules which govern human interactions (Barrett, 2005; Fafchamps, 2004; Jayne et al., 2010; Kijima et al., 2013; Poulton et al., 2006). Such observations have prompted the use of systems approach to analyse the barriers to technology adoption. The agricultural innovation systems (AIS) approach recognises the role of the institutional and policy context in adoption of agricultural technologies (Klerkx et al., 2012; Leeuwis and Aarts, 2011; Rajalahti et al., 2008; van Mierlo et al., 2010). The AIS approach, however, has not been widely used to analyse the constraints to technological adoption in livestock production under the developing country setting. A holistic understanding of technology adoption by the smallholder requires a conceptual framework which allows the analysis of factors affecting technology adoption at different aggregation levels: farm households, value chain and institutions and policies.

1.2. Problem statement and research objectives

Policy-makers and development practitioners need insights about the underlying reasons for low adoption of technologies that enhance livestock production and livestock water productivity for programme formulation and implementation. Despite considerable work done on technology adoption in the past, there is a shortage of scientific evidence on factors situated at different aggregation levels which affect technology adoption in the livestock sector. The overall objective of this study was to explore the factors affecting adoption of technologies that enhance the productivity of livestock production and water use efficiency in Ethiopian highlands, with particular emphasis on dairy production. This study assessed factors that affect technology adoption and rainwater use efficiency in the broader context by integrating household, value chain, institutions and policies. Understanding the factors affecting technology adoption and rainwater use efficiency could provide insights on the underlying constraints that hinder technology adoption by the smallholders. This knowledge in turn allows us to identify interventions that help overcome the constraints or mitigate the adverse effects of the constraints to technology adoption in livestock production.

This study has four interrelated objectives:

1. To identify factors explaining the variation in LWP within and among farming systems in Ethiopian highlands.
2. To identify the factors that affect adoption of dairy technologies by smallholders.
3. To assess the impact of improved dairy technologies on household nutrition and household income.
4. To identify socio-economic and policy constraints that affect technology adoption in the dairy sector in Ethiopia.

1.3. Analytical framework

The analytical framework depicts relevant factors that could affect adoption of technology at the levels of farm households, the value chain, and institutions and policies (Figure 1). We used a combination of methodological approaches from various disciplines, including farming systems analysis, quantitative modelling and innovation systems approach to identify the factors at three aggregation levels that affect technology adoption.

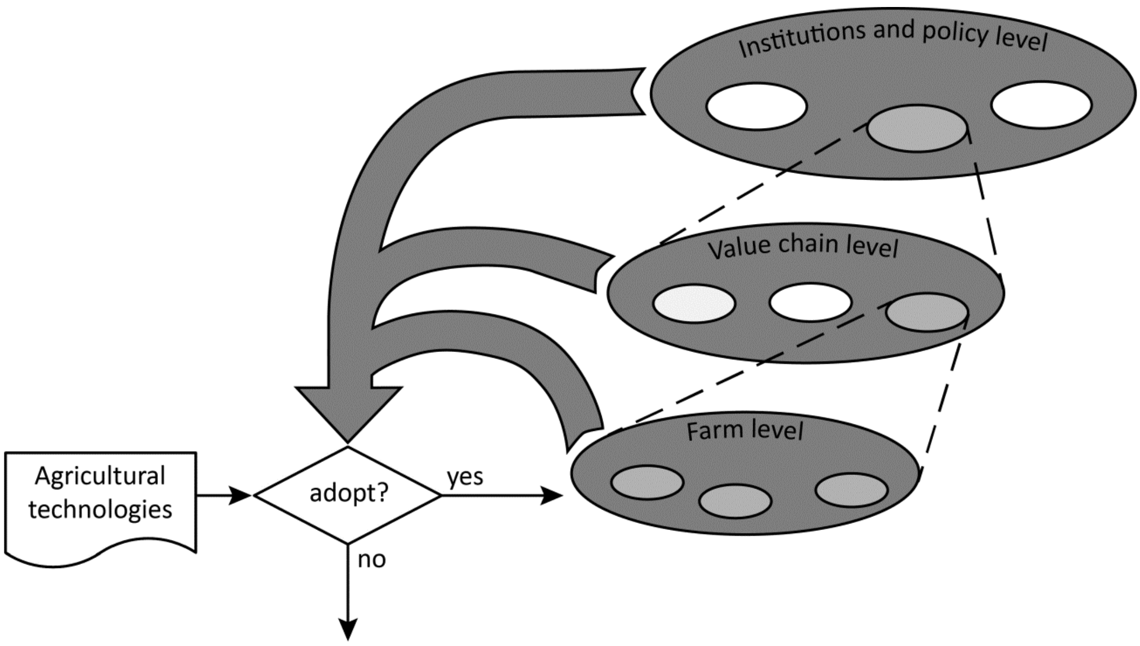

Figure 1. Conceptual model for analysing the technology adoption process in the livestock sector

1.4. Context and description of study area

The majority of Ethiopian population (80 %) live in rural areas and depend on agriculture for their livelihoods. Livestock production plays important and multiple roles in Ethiopian economy (Admassie and Abebaw, 2014). Ethiopia has the largest livestock population in Africa comprising 54 million cattle, 25.5 million sheep, 24.1 million goats and 0.9 million camels in 2012 (FAOSTAT, 2014). Livestock animals provide basic products, such as milk, meat, hides and cash income to the households. In addition to the basic products, livestock also fulfil a number of functions such as traction power, manure, employment generation, store of wealth and socio-cultural functions (Ayalew et al., 2003; Mwacharo and Drucker, 2005; Udo et al., 2011). Mixed crop-livestock production is the common farming system in the Ethiopian highlands. The main purpose of keeping cattle in mixed crop-livestock production systems is to get oxen that are needed to perform farm operations, such as tilling crop lands (Kebebe et al., 2014). Despite having the largest cattle stock in Africa and a favourable environment for dairy farming, milk production in Ethiopia is below its potential. The dairy sector in the Ethiopian highlands is characterised by subsistence oriented production, low use of technological inputs and underdeveloped markets for inputs, services and outputs (Ahmed et al., 2004). About 81% of the total annual milk production is accounted by low yielding indigenous cattle (FAOSTAT, 2014). In terms of market development, markets for dairy products are underdeveloped in rural areas and own-consumption shares are very high (Duncan et al., 2013; Francesconi et al., 2010; Hoddinott et al., 2014).

This research was carried out in three districts: Fogera, Jeldu and Diga in the Blue Nile Basin (locally known as Abay basin) in the Ethiopian highlands (Figure 2). The research was part of the larger Nile Basin Development Challenge (NBDC) research for development project in Ethiopia. The NBDC research programme ran from 2010 to 2013 and its aim was to improve the resilience of rural livelihoods in the Ethiopian highlands through a landscape approach to rainwater management (Merrey, 2013; Sharma et al., 2012). This research contributes to the research theme related to developing integrated rainwater management strategies (Detailed description of the project and the study area is given in **Chapter 2**).

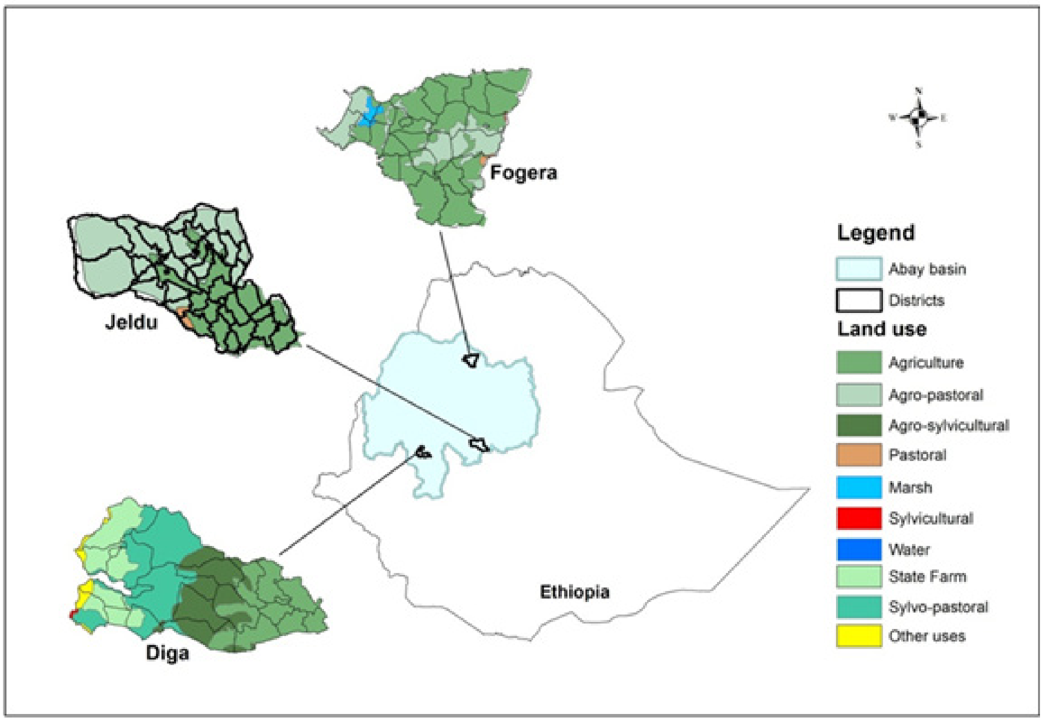

Figure 2. Map of study area

1.5. Outline of the thesis

The studies described in **Chapters 2 to 5** were each dedicated to specific objectives in order to address the research questions. Together they contribute to addressing the central research question which motivated this study (Figure 3). The second chapter characterised the farming systems in the study area and explored the effect of household demographic characteristics and farm assets on livestock water productivity within and among farming systems, using the analysis of variance and multilevel mixed effect linear regression. The third chapter assessed the difference between adopters and non-adopters of dairy technologies in farm resource endowments and access to input and output markets using chi-square test. The fourth chapter examined the difference in nutrition status and income between adopters and non-adopters of dairy technologies, using propensity score matching and a sample treatment effect estimator. The fifth chapter assessed how institutions and policies affect farmers' technology adoption in the dairy sector. The results obtained from different chapters were analysed in the sixth chapter to provide an overall picture of the complex factors affecting agricultural technology adoption. Finally, the sixth chapter concludes the thesis by highlighting a few implications for development intervention, policy formulation and for future research.

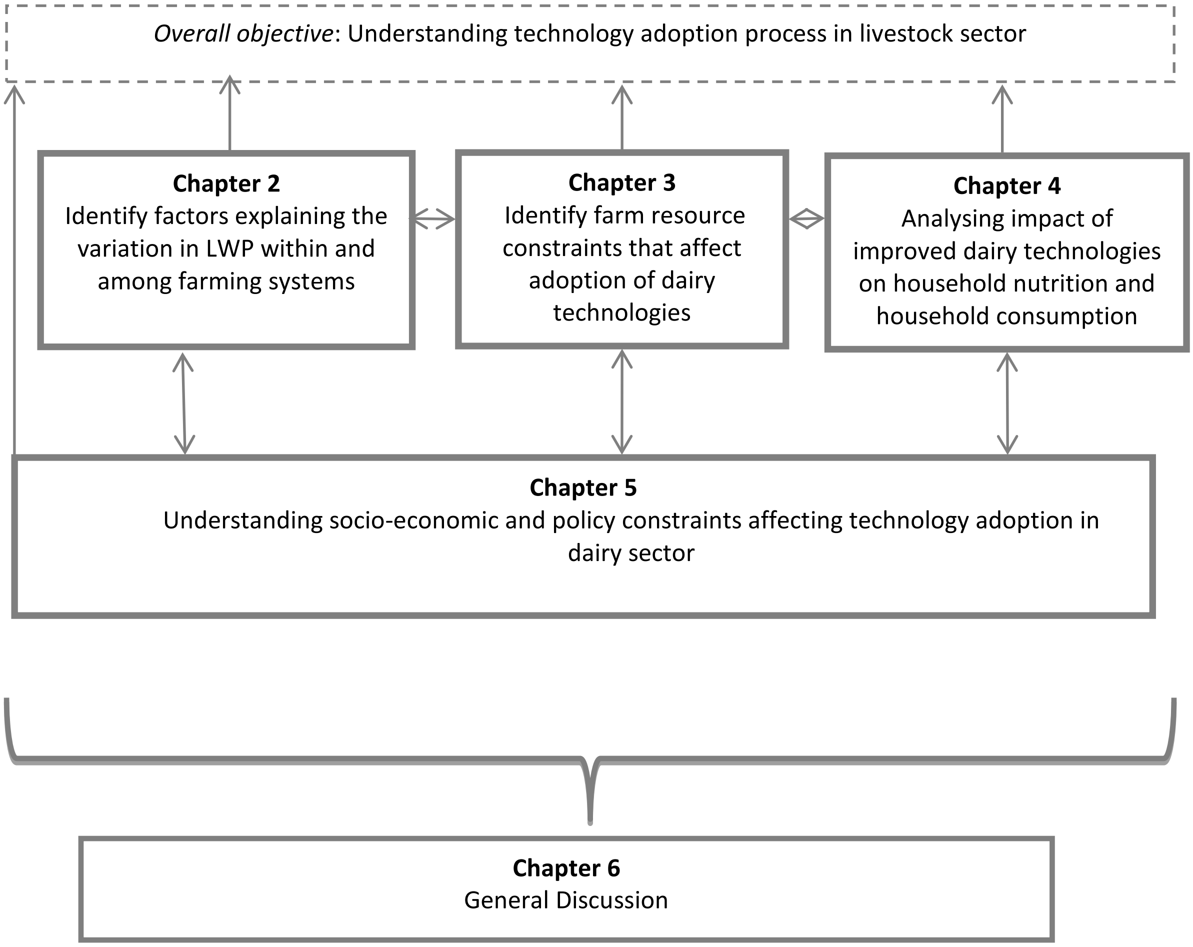

Figure 3. Schematic outline of thesis chapters

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Chapter 2

Strategies for improving water use efficiency of livestock production in rain-fed systems

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Abstract

Livestock production is a major consumer of fresh water and the influence of livestock production on global fresh water resources is increasing due to the growing demand for livestock products. Increasing water use efficiency of livestock production, therefore, can contribute to the overall water use efficiency of agriculture. Previous studies have reported significant variation in livestock water productivity (LWP) within and among farming systems. Underlying causes of this variation in LWP require further investigation. The objective of this paper was to identify factors which explain the variation in LWP within and among farming systems in Ethiopia. We quantified LWP for various farms in mixed crop-livestock systems and explored the effect of household demographic characteristics and farm assets on LWP using the analysis of variance and multilevel mixed effect linear regression. We focused on water used to cultivate feeds on privately owned agricultural lands. There was a difference in LWP among farming systems and wealth categories. Better-off households followed by medium households had the highest LWP, while poor households had the lowest LWP. Regression results showed that age of household head, the size of the livestock holding and availability of family labour affect LWP positively. The results suggest that water use efficiency could be improved by alleviating resource constraints such as access to farm labour and livestock assets, oxen in particular.

2.1. Introduction

The global demand for fresh water to feed the world's growing population is projected to increase. Part of this increase in demand for water will be in areas that rely on rain-fed agriculture (Wisser *et al.*, 2010). The availability of rainwater is, however, limited because of the finite amount and uneven distribution of precipitation. Agricultural seasons in Ethiopia are characterized by high-intensity precipitation extremes followed by long dry periods, which result in water scarcity during the dry season (Alemayehu *et al.*, 2012). The severity of water scarcity has prompted researchers, practitioners and policymakers to recognise water scarcity as an important constraint to increased food production over the next few decades (Hoekstra *et al.*, 2009). Therefore, maximizing yield per unit of rainwater has become an important management issue (Ali and Talukder, 2008; Bossio, 2009; Molden et al., 2010; Rockström et al., 2010). Strategic measures are, therefore, needed to increase the productivity of rainwater in agricultural production.

Livestock production is one of the major consumers of fresh water (Amede et al., 2009a; Diogo et al., 2010; Molden et al., 2010; Peden et al., 2009). Globally, livestock production accounts for about 20% of agricultural evapotranspiration (ET_a) (Molden *et al.*, 2010). Water used to grow livestock feed is far greater than water needed to meet the drinking requirements of livestock. Drinking water accounts for only about 2% of the total water need for livestock production with much of the remainder being accounted for by water needed for feed production (Peden *et al.*, 2007). Increasing the efficiency of water used for livestock feed production could reduce future demands for agricultural water. Peden *et al.* (2007) defined livestock water productivity (LWP) as the ratio of beneficial livestock outputs and services to actual evapotranspiration (ET_a) of water in the production of livestock feeds. In mixed crop-livestock systems, the concept of LWP is a measure of the ability of the livestock production system to convert available rainwater into beneficial livestock outputs and services.

Different studies have estimated LWP in mixed crop-livestock systems in Ethiopia (Amede et al., 2009b; Descheemaeker et al., 2010; Gebreselassie et al., 2009; Peden et al., 2009). These studies show significant variation in LWP within and among farming systems, indicating a scope for improving LWP. We need insights into the factors that explain the observed variation in LWP to identify opportunities for improving LWP in mixed crop-livestock systems. To our knowledge, no study has systematically explored the factors that explain the variation in LWP between farming systems and farm households. Thus, we lack the information needed to determine where to best invest resources in order to improve livestock water productivity. Therefore, the objective of this paper is to identify the factors that explain the variation in LWP within and between farming systems, taking Ethiopia as a case. We quantified LWP for various farms in diverse mixed crop-livestock systems and explored the effect of a range of factors including household demographic characteristics, farm assets and wealth status on LWP, using analysis of variance and multilevel mixed effect linear regression.

2.2. Materials and Methods

2.2.1. Description of the study areas

This research was part of the larger Nile Basin Development Challenge (NBDC) research for development project in Ethiopia. The NBDC research program ran from 2010 to 2013, and aimed to improve the resilience of rural livelihoods in the Ethiopian highlands through a landscape approach to rainwater management (Merrey, 2013; Sharma et al., 2012). The present study contributes to the research theme related to developing integrated rainwater management strategies. The research was carried out in three districts: *Fogera, Jeldu* and *Diga* in the Blue Nile Basin (locally known as *Abay* basin) in Ethiopia (Supplementary Figure S1). The three districts represent different agro-ecological zones and livelihood systems. Farmers practice low-input rain-fed agriculture, which results in low levels of production. Farming is basically subsistence oriented, implying that many farmers produce just enough to sustain their own families. Household resources (e.g., land, labour, local breeds of livestock) are the main production inputs used by the farmers. The mixed crop-livestock system is the dominant farming system in these districts. As the emphasis of this research is on assessing strategies to improve the efficiency of rainwater used in livestock production, we focused on the major contributor to this, i.e., crops grown under rain-fed conditions to provide both food grains and crop residues for livestock feed. We also considered feed from private grazing lands.

The *Fogera* district is located in the north-eastern part of the Blue Nile Basin, close to *Lake Tana* (Supplementary Figure S1). The altitude ranges from 1800 to 2410 meters above sea level (masl) in the uplands and from 1774 to 1800 masl in the flood plains. Annual rainfall ranges from 1101 to 1651 mm. The district comprises a large flat floodplain in the vicinity of the lake and undulating landscape in the uplands. Farmers in the flood plains practice relay cropping of grass pea (*Lathyrus hirsutus*) after the rice harvest using residual moisture. The majority of farmers in the district keep indigenous breeds of cattle, sheep, goats and equines to sustain their livelihoods. As in mixed systems in other developing countries (Diogo et al., 2010; Herrero et al., 2013; Udo et al., 2011), the purpose of livestock rearing in the district encompasses provision of milk, meat and hides, traction, manure, standing asset and socio-cultural functions. Livestock is also used as an income buffer and is sold to cope with temporary shortfalls in income. Most households have no savings account, other than the market value of their livestock. Smallholder farmers often save some surplus income in livestock. Sheep and goats are particularly kept for cash income and meat. Equines are used as pack animals for transportation. On the other hand, livestock makes use of crop residues that would otherwise go to waste. The major sources of feed for livestock in the district include crop residues and grazing on natural pasture (from private and communal grazing lands), seasonal fallow lands and road sides. Experts and farmers in the districts estimated that over 50% of livestock feed comes from crop residues. The contribution of supplementary feeds such as brans, oilseeds and other agro-industrial by-products is negligible.

Jeldu district is located in the south-western part of the Blue Nile Basin (Supplementary Figure S1). The altitude ranges from 1480 to 2880 masl in the district. Mean annual rainfall ranges from 856 to 1010 mm. Teff (*Eragrostis tef*) straw, wheat straw and barley straw are used for livestock feed, particularly during dry seasons. Livestock rearing at *Jeldu* serves similar purposes outlined for *Fogera*, except that the role of horses as pack animals is more prominent at *Jeldu*.

Diga district is located in the south-western part of Blue Nile Basin (Supplementary Figure S1). The altitude ranges from 1338 to 2180 masl in the district. Mean annual rainfall ranges from 1101 to 1936 mm. Distinct from the other two districts, fallow land and stubble grazing is very common at *Diga*. After harvesting the grain, animals are allowed to graze freely on the stubbles of maize and sorghum fields. Crop residue is mainly left in the fields for livestock grazing. While the purpose of livestock rearing is similar to that of *Fogera*, farmers at *Diga* commonly use manure for soil fertility improvement through a corralling system. The use of manure for fuel is not common at *Diga*.

2.2.2. Household survey design and data collection

For this study, data were collected using a household survey. One watershed within each district was selected to implement the survey. In each watershed, we selected villages and farm households using a multi-stage sampling technique. First, three villages were selected within the selected watershed. Second, farm households were randomly selected from a list of all the farmers in a given village. In total, 220 households, comprising 62 households from *Fogera*, 91 households from *Jeldu* and 67 households from *Diga* districts were selected for the survey. Using a pre-tested questionnaire, we collected information on household demographics, household assets such as land, labour and livestock holdings, and major livelihood activities, including crops, livestock and other economic activities, during October-December, 2011. The questionnaire was completed through interviews with the household head or, in his/her absence, the most senior member available in the household. Through the household survey, we collected information on crop types, area under each crop and production of each crop, livestock herd structure, production and services. Feed resources from communal grazing lands contribute to the total livestock feed supply in the mixed crop-livestock systems. However, accurately estimating area under communal grazing lands and its biomass yields was not possible in household surveys. In our household survey, the area under communal grazing land was estimated as 0.40 ha at *Fogera*, 0.24 ha at *Jeldu*, and 0.20 ha at *Diga* per household. This was rough estimate of the available communal grazing lands. Our household survey methodology could not generate reliable information about the total area under communal grazing lands, biomass yield, number of users of the communal grazing land and the intensity of use by individual households. Therefore, area under communal grazing land was not included in the analysis. The focus in the present study was, therefore, on water use in feed production from land owned by individual farmers. Hence, we focused on data collection in areas under private grazing and crop production for each household. The dry matter productivity of private grazing land was estimated using existing grazing land productivity benchmarks. Several studies reported grazing land biomass yields ranging from 0.4-12 tonne dry matter ha^{-1} yr^{-1} (Borrion et al., 2012; Gabrielle and Gagnaire, 2008). In our study a productivity of 2 tonne dry matter ha^{-1} yr^{-1} (Henricksen and Pauw, 1988) was used as a bench mark to estimate total dry matter production in grazing lands because the study by Henricksen and Pauw (1988) was more representative of the present study areas.

To enable comparison of farming systems, households were clustered into farming systems based on the dominant crops grown by the farmers. Categorisation of sample households into farming systems is relevant because households pursue different livelihood strategies in each farming system to take advantage of the available agricultural potential. Accordingly, seven farming systems were identified. Fogera had two farming systems: teff-millet in the uplands and rice pulse in the flood plains. Jeldu had three major farming systems: barley-potato in the uplands, wheat-teff in the midlands and maize-sorghum in the lowlands. Diga had two major farming systems: teff-millet in the midlands and maize-sorghum in the lowlands. To enable a comparison of wealth categories, farm households were also categorised into three wealth categories, i.e. poor, medium and better-off, based on farmers' self-reported wealth rankings.

2.2.3. Computation of livestock water productivity (LWP)

LWP is defined as the ratio of beneficial livestock outputs and services to actual evapotranspiration (ET_a) of water in the production of livestock feeds (Descheemaeker et al., 2010; Haileslassie et al., 2009; Peden et al., 2007). Evapotranspiration related to the actual production of above ground biomass (ET_a in millimeters per crop growth period) was computed based on the relation between potential evapotranspiration (ET_c) and crop yields, collected through farmer recall interview (Fermont and Benson, 2011). To determine ET_c, we first used the FAO Penman-Monteith equation to estimate evapotranspiration of the reference crop (ET_0). The Penman-Monteith equation determines the evapotranspiration from the hypothetical grass reference surface and provides a standard to which the evapotranspiration of other crops can be related (De Boer *et al.*, 2013). Climate data (temperature, wind speed, precipitation) were estimated using New LocClim (Grieser et al., 2006), which uses observations from meteorological stations to predict climate data at a given location by interpolation. Second, potential evapotranspiration of the crop (ET_c) was computed by multiplying ET_0 with the crop coefficients K_c (Allan, 1998). The crop coefficient is determined by crop type and the stage and length of growing period. The length of growing period was determined for each crop in the districts based on estimates generated by New LocClim. Soil data was taken from literature values corresponding to the study areas (Haileslassie *et al.*, 2009). Actual yield of each crop for the main cropping season in 2011 was collected from the sample households using face to face interviews. Finally, the ET_a for each crop type was computed based on ET_c and additional data on soil and actual crop yields, using CropWat 8.0 software (Muñoz and Grieser, 2006).

In a multiple-output situation, such as cultivation of wheat producing grain and crop residues, we allocated ET_a to the multiple outputs based on their relative economic values (Borrion et al., 2012; Gabrielle and Gagnaire, 2008). The harvest index (HI) and crop yield were used first to compute the mass value of various products produced per ha (Haileslassie et al., 2011). Subsequently, mass values were multiplied by their economic values to compute relative economic values of various products.

Livestock beneficial outputs and services including milk, livestock off-take, manure, traction, threshing and transportation were estimated in monetary values. All livestock types kept by the households were considered in calculating livestock beneficial outputs and services. Livestock off-take was defined as the proportion of animals sold or slaughtered for home consumption in a year. Off-take of livestock was calculated by summing the values of each animal type (in US$) that was sold, slaughtered for home consumption or gifted out in a year. To estimate the values of these products and services, information on the livestock herd structure, productivity and services given in a year were calculated as suggested by Haileslassie *et al.* (2009) and Descheemaeker *et al.* (2010). Haileslassie *et al.* (2009)

developed a simple spread sheet model to estimate LWP values. The model can be specified mathematically as follows:

$$LWP_i = \frac{\sum_{i=1}^{n}(O_i * P_i + S_i * P_i)}{\sum_{k=1}^{n} WD_k} \qquad (1)$$

where i denotes a unit of observation, LWP is livestock water productivity, O_i is quantity of i^{th} livestock output (e.g. milk, meat, manure), S_i is service type (e.g. traction) obtained per year, P_i is local market price (US$) of the i^{th} output and i^{th} service type; WD_k is the amount of water depleted in evapotranspiration for production of k^{th} animal feed resources (e.g. on crop residues).

2.2.4. Statistical analysis

The difference in means of farm resources, beneficial outputs and LWP among farming systems and wealth categories were tested using one-way analysis of variance (ANOVA). Tukey's HSD test was used for the multiple mean comparisons (Gauch, 1988). Similarly, one-way ANOVA was used to test the differences in farm resources, sub-components of beneficial livestock outputs and LWP among wealth categories. The root mean square error (RMSE) is given in an addition column for ANOVA results as an indicator for model precision.

Furthermore, we used multilevel mixed effect linear regression model to test the hypothesized relationships between LWP and the range of explanatory variables defined below. Multilevel mixed effect linear regression model which allows the analysis of both fixed effects, due to the explanatory variables, and random effects due to clustering by the farming system (Goldstein, 1986; Horton, 2006). The multilevel mixed-effect linear regression model for livestock water productivity is specified as:

$$Y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \beta_{41} x_{i4} + \beta_5 x_{i5} + \beta_6 x_{i6} + \beta_7 x_{i7} + \beta_8 x_{i8} + Zu_i \; (2)$$

where Y_i represents LWP, β_0 is the intercept, $\beta_1 - \beta_8$ are regression coefficients of the explanatory variables which represent fixed effect, X_{i1} is age of household head, X_{i2} is gender of household head (1=male, 0=female), X_{i3} is education level of household head, X_{i4} is family labour, X_{i5} is land holding size, X_{i6} is total livestock holding, X_{i7} is farmers wealth status, X_{i8} is value of crop production, Z is the random effect due to clustering by farming system and u_i is the error term. The model was fitted for households across all districts. All statistical analyses were carried out with Stata 12 (StataCorp, 2011).

2.2.5. Description of factors explaining the variation in livestock water productivity

We included the key factors that influence LWP based on theoretical grounds and on previous empirical research on LWP (Knowler and Bradshaw, 2007; Peden et al., 2007; Peden et al., 2009). We included factors that affect livestock output and services (numerator of the water productivity equation) and water consumption in feed production (denominator of the same equation). Poor water management is common in sub-Saharan Africa, which implies that socio-economic factors influence the optimum level of LWP (Rockström *et al.*, 2010). Farmers make decisions about the cropping pattern depending on their resource endowment and food security objectives. Many non-water related factors, such as shortages of draught oxen and family labour, inadequate access to capital for investments and limited skills of farmers, influence agricultural production in rain-fed agriculture (Rockström *et al.*, 2010). The explanatory variables included in the analysis and their postulated effects on livestock water productivity are discussed below.

Age of household head (years): Age of household head can be considered as an indicator of experience in farming. On the other hand, older farmers may not have physical strength to implement labour intensive rainwater management practices. Hence, the effect of age on use of new rain-water management practices is ambiguous.

Gender (male = 1 and female = 0): Women in Ethiopia play important roles in livestock production such as cattle feeding, barn cleaning, calf rearing, milk handling and marketing, but they are often locked out of land ownership, access to productive farm inputs and support from extension services. These challenges mean that, on average, female farmers produce less per hectare than men, which adversely affects livestock water productivity (Marenya and Barrett, 2007). Therefore, the gender of household head being female could be negatively associated with LWP.

Education level of household head (years): Education level is expected to have a positive influence on the use of improved crop and livestock husbandry practices because of the assumed link between education and knowledge (Knowler and Bradshaw, 2007; Rahm and Huffman, 1984).

Family labour (in adult equivalents): The use of better land and water management practices requires sufficient family labour. Shortage of family labour can prevent implementation of better agronomic practices (e.g. timely planting and weeding) that has potential to increase crop productivity (Giller *et al.*, 2011a). We hypothesize that households' productive labour force is positively associated with livestock water productivity.

Total land holding (ha): Larger land holdings are associated with greater wealth and increased availability of capital. Farmers with larger landholdings are more likely to invest in land and water management practices that increase LWP (Hanjra et al., 2009; Jayne et al., 2010). Therefore, the size of landholding is expected to have a positive influence on LWP.

Livestock holdings (in TLU): Livestock provide replacement oxen, which are the main source of draught power for land preparation and manure for soil fertility replenishment (Sasson, 2012). Particularly, availability of oxen for land cultivation is an important factor in determining the level of above ground biomass production in mixed crop-livestock production systems in Ethiopia (Haileslassie *et al.*, 2006). Shortage of traction oxen for timely agronomic practices can limit the size of the cropped area and also yields. Ownership of large numbers of livestock provides the opportunity to generate beneficial output from feeds and improve overall LWP. The effect of livestock holding on LWP is, therefore, expected to be positive.

Grain yield (kg): There is a well-established positive linear relationship between plant biomass and transpiration (Rockström, 2003). Crop residues are the major livestock feed component in mixed crop-livestock systems. Hence interventions that improve crop water productivity in plant biomass production also improve livestock water productivity. Hence better crop yield is expected to have a positive influence on LWP. The value of grains was used to facilitate comparison of total crop production between farming systems and wealth categories with different crop compositions.

Wealth category was included as one of the explanatory variables in the regression to control for the effects which may not be accounted by major farm resources such as land and livestock holdings. The effects of farming system was considered as a clustering variable in the model to control the random effect.

2.3. Results

In this section we present the results of ANOVA and regression analysis. First, we present the ANOVA results of farm resources, livestock beneficial outputs and LWP for farming systems and wealth categories.

2.3.1. Farm characteristics, water used in livestock feed production, livestock beneficial outputs and LWP by farming systems

Means of farm characteristics and LWP for the farming systems are presented in Table 1. Differences were found between farming systems with regard to labour and land holdings. Farmers in wheat-teff farming systems at *Jeldu* (FS4) had more family labour than farmers in other farming systems. Farmers in wheat-teff farming systems at *Jeldu* (FS4) and in teff-millet (FS6) and maize-sorghum farming system at *Diga* (FS7) had relatively more land than farmers in other farming systems. The total value of grain products, the amount of rainwater evapotranspired in livestock feed production and LWP were different among farming systems. LWP was relatively higher in teff-millet (FS1) and rice-pulse (FS2) farming systems at Fogera. There was no clear difference, however, in total beneficial livestock output between any of the farming systems. The difference in LWP mirrored the difference in the amount of rainwater evapotranspired in livestock feed production.

Table 1. Means of farm resources and livestock water productivity of households in different farming systems in each district

Farm characteristics	Districts							RMSE[¥]
	Fogera		Jeldu			Diga		
	*FS1 (n= 32)	FS2 (n= 30)	FS3 (n= 31)	FS4 (n= 30)	FS5 (n= 30)	FS6 (n= 35)	FS7 (n= 32)	
Family labour (in adult equivalent)	3.67[ab]	3.31[a]	3.86[ab]	4.94[b]	4.04[ab]	3.74[ab]	3.98[ab]	1.58
Area under food-feed crops (ha)	1.59	1.70	1.62	2.14	1.77	1.69	1.82	0.71
Area under private grazing (ha)	0.30[a]	0.17[a]	1.28[c]	0.76[b]	0.52[ab]	0.42[ab]	0.58[ab]	0.41
Area under other uses (ha)	0.13[a]	0.05[a]	0.03[a]	0.03[a]	0.00[a]	0.42[b]	0.60[b]	0.25
Total land holding area (ha)	2.02[ab]	1.92[a]	2.93[c]	2.92[c]	2.29[abc]	2.54[abc]	3.10[bc]	1.01
Livestock holding (TLU**)	5.97	5.14	4.48	6.67	4.96	5.43	5.67	3.41
Oxen owned (TLU)	2.24	1.89	2.36	2.65	2.10	2.09	2.21	1.48
Value of grain products ('000 US$ yr^{-1})	0.13[ab]	0.30[d]	0.30[d]	0.24[cd]	0.20[bc]	0.12[a]	0.19[abc]	0.09
Evapotranspiration on total private agricultural land ('000 m^3 yr^{-1})	6.16[a]	8.02[ab]	10.18[bc]	12.23[c]	9.06[abc]	7.93[ab]	10.17[bc]	3.85
Evapotranspiration in feed production ('000 m^3 yr^{-1})	2.70[a]	2.55[a]	5.90[bc]	6.58[c]	4.46[abc]	4.25[ab]	5.57[bc]	2.41
Evapotranspiration from food-feed crops ('000 m^3 yr^{-1})	1.83[a]	2.00[a]	4.53[b]	3.27[ab]	3.02[ab]	3.51[ab]	4.08[b]	1.92
Evapotranspiration from private grazing ('000 m^3 yr^{-1})	0.87[a]	0.56[a]	1.37[a]	3.31[b]	1.44[a]	0.74[a]	1.50[a]	0.10
Beneficial livestock output ('000 US$ yr^{-1})	0.91	0.74	0.88	1.09	0.78	0.68	0.75	0.60
Livestock water productivity (US$ m^{-3})	0.34[c]	0.29[bc]	0.14[a]	0.17[a]	0.18[ab]	0.17[a]	0.13[a]	0.13

[¥]RMSE denotes the root mean square error

[a-d] Values within a row with different superscripts differ significantly at P<0.05

**FS1=Teff-Millet-Fogera, FS2=Rice-Pulse-Fogera, FS3=Barley-Potato- Jeldu, FS4=Wheat-Teff-Jeldu, FS5=Sorghum-Teff-Jeldu, FS6=Teff-Millet-Diga, FS7=Maize-Sorghum-Diga*

[**]TLU= Tropical livestock unit using a conversion factor of a mature animal weighing 250 kg (ILCA, 1990)

2.3.2. Farm characteristics, water used in crop residue production, livestock beneficial outputs, and LWP by wealth category

Farm characteristics and LWP for different wealth categories are presented in Table 2. The average family labour per household was higher in better-off and medium wealth categories as compared to poor household categories. The average land holding was higher for households in better-off followed by medium wealth categories. The area under food-feed crop production and area under grazing among wealth categories followed the same pattern as the total land holding. The average livestock and oxen holdings were higher in better-off and medium wealth categories than in the poor household categories. Average livestock holding per unit of land were also higher in better-off than in poor households. The amount of water depleted for feed production, the value of livestock outputs/services and livestock water productivity were higher for better-off and medium household categories than for poor household categories (Table 2).

The mean values of major livestock beneficial outputs and services across different wealth categories show that better-off households followed by medium households derived the highest benefits from livestock outputs and services, while poor households derived the

Table 2. Means of farm resources and livestock water productivity of households in different wealth categories

	Wealth categories			
Farm characteristics	Better-off (n=75)	Medium (n=70)	Poor (n=75)	RMSE[¥]
Family labour (in adult equivalent)	4.62[b]	4.12[b]	3.05[a]	1.50
Total land holding (ha)	3.47[c]	2.41[b]	1.81[a]	0.82
Area under food-feed crops (ha)	2.38[c]	1.70[b]	1.19[a]	0.53
Area under private grazing (ha)	0.78[b]	0.56[ab]	0.51[a]	0.54
Area under other uses (ha)	0.30[b]	0.15[a]	0.11[a]	0.32
Livestock holding (TLU)	9.37[c]	4.89[b]	2.13[a]	1.62
Livestock holding per land holding (TLU/ha)	2.62[c]	2.11[b]	1.32[a]	1.00
Oxen owned (TLU)	3.53[c]	2.09[b]	1.02[a]	1.06
Value of grain products ('000 US$ yr^{-1})	0.24[b]	0.20[ab]	0.18[a]	0.11
Total evapotranspiration on private land ('000 m^3 yr^{-1})	12.88[c]	8.43[b]	5.85[a]	3.03
Evapotranspiration in feed production on area under food-feed crops ('000 m^3 yr^{-1})	4.56[c]	2.85[b]	2.12[a]	1.84
Evapotranspiration in feed production on private grazing lands ('000 m^3 yr^{-1})	2.21[c]	1.27[b]	0.65[a]	1.57
Evapotranspiration in feed production on private land ('000 m^3 yr^{-1})	6.77[c]	4.12[b]	2.77[a]	2.21
Beneficial livestock output ('000 US$ yr^{-1})	1.45[c]	0.71[b]	0.33[a]	0.38
Livestock water productivity (US$ m^{-3})	0.26[b]	0.20[ab]	0.16[a]	0.15

[¥] *RMSE denotes the root mean square error*

[a-c] *Values within a row with different superscripts differ significantly at P<0.05*

lowest benefits from livestock outputs and services (Table 3). Among the types of livestock beneficial outputs and services, traction accounted for the largest share of beneficial outputs regardless of wealth categories.

Table 3. Means of livestock beneficial outputs and services of households in different wealth categories (US$ yr^{-1})

	Wealth categories			
Livestock beneficial outputs and services	Better-off (n=75)	Medium (n=70)	Poor (n=75)	RMSE[¥]
Milk	233.72[c]	120.08[b]	48.92[a]	137.71
Off-take	187.03[b]	91.01[a]	56.49[a]	137.23
Manure	223.71[c]	120.96[b]	55.06[a]	44.09
Traction	597.54[c]	280.10[b]	130.71[a]	174.48
Threshing	50.37[c]	21.46[b]	8.61[a]	28.84
Transport	156.54[c]	72.15[b]	25.29[a]	99.47
Total	1448.92[c]	705.77[b]	325.08[a]	382.56

¥RMSE denotes the root mean square error

a-c Values within a row with different superscripts differ significantly at P<0.05

2.3.3. Factors explaining livestock water productivity

The age of household head was negatively associated with LWP. The effects of livestock ownership and the size of family labour on LWP were positive, while the size of land holding had a negative effect on LWP (Table 4).

Table 4. Multilevel mixed effect model estimates of factors explaining variation in Livestock Water Productivity (LWP in US$ m^{-3})

Variables	LWP[§]
Age of household head (yrs)	-0.11 (0.05)**
Gender of household head (1=male, 0=female)	2.26 (2.86)
Education level of household head (yrs)	0.47 (0.58)
Family labour (adult equivalent)	1.55 (0.48)***
Land holding (ha)	-8.14 (1.03)***
Livestock holding (TLU)	2.46 (0.43)***
Value of grain products (US$ yr^{-1})	0.01 (0.01)
Farmer's wealth status (1=better off, 2=medium, 3=poor)	-2.9 (1.89)
Constant	30.10 (8.25)***
Number of observations	220

*Standard errors in parentheses, * p<0.05, *** p<0.001*

§LWP was multiplied by constant number (100) to improve presentation of coefficients

2.4. Discussion and conclusions

While rainwater plays an important role in crop and livestock production in mixed crop-livestock farming systems, the increasing scarcity of fresh water resources has raised concerns about the conversion efficiency of rainwater into beneficial outputs. Building on previous research on LWP, this study assessed differences in LWP among farming systems and wealth categories and explained variation among individual households on the basis of household characteristics.

Results show significant differences among farming systems in family labour, land holding, total value of grain products, amount of rainwater evapotranspired in livestock feed production and LWP. Nevertheless the differences were small. The allocation of area under food-feed crop production and area under grazing in the farming systems followed the same pattern as the total land holding. The difference in LWP among farming systems could be attributed to the difference in the amount of rain-water evapotranspired in feed production across farming systems. The LWP values found in our analysis were generally low and comparable with the values reported by other researchers (Amede et al., 2009b; Peden et al., 2009; van Breugel et al., 2010). The LWP values were particularly low in farming systems dominated by barley-potato and maize-sorghum crop mixtures. The observed low LWP values in most farming systems can partly be attributed to low level of meat and milk production per animal. As a consequence, the water requirements for maintenance, growth and milk production are very high in these systems (van Breugel *et al*., 2010). The low level of LWP reported in the farming systems could also be associated with the widespread land degradation in the Ethiopian highlands (Alemu and Kidane, 2014; Kato et al., 2011). Land degradation leads to low grain and crop residue yields and consequently to low livestock beneficial outputs and services and LWP.

The higher LWP under teff-millet and rice-pulse based farming systems at Fogera can be attributed to the double cropping practice that exploits the residual moisture after the end of the main rainy season. This practice favours the availability of more crop-residues as supplemental feed resources during dry season at times when feed supply becomes critical (Alemayehu et al., 2009). The variation in LWP among wealth categories can be partly explained by the differences in the ownership of livestock, access to labour and other household assets. As households in better-off and medium wealth categories own more livestock per unit area, they can take advantage of their larger herds to convert available feed from crop residues and grazing lands into higher beneficial outputs such as milk, meat and traction services. The higher beneficial livestock outputs ultimately contribute to higher LWP. This implies that farmers with low livestock numbers cannot efficiently utilize crop residues and feeds from grazing lands. This result corroborates the findings of Haileslassie *et al.* (2009) who found that most of the beneficial outputs in Ethiopian highland come from ownership of higher numbers of livestock. The variation observed in the total beneficial livestock output among wealth categories mirrors the difference in the number of oxen kept by farmers in different wealth categories. The higher livestock beneficial outputs and services among better-off farmers could also be due to the fact that wealthy farmers can afford to keep healthy animals through provision of better animal healthcare and nutritious feeds to their animals (Peden *et al.*, 2009). The difference in LWP between wealth categories indicates the possibilities to increase LWP with existing level of knowledge provided farmers have better access to important farm resources (e.g. land and traction oxen) and allocate land to crops that use rain-water efficiently. Our findings on LWP are consistent with previous findings that households in better-off and medium wealth categories recorded higher values of total beneficial output and LWP (Haileslassie *et al.*, 2009).

Although water use in communal grazing land was not included in our analysis, due to difficulties in accurately estimating the areas under communal grazing and its corresponding water use, we suspect that the variation in LWP among farming systems and wealth categories could partly be explained by feed from communal grazing lands. For example, Fogera district has relatively more communal grazing lands, which gives farmers more feed from communal grazing and hence higher LWP. Similarly, richer farmers with higher number of livestock may have better grazing opportunities on communal grazing lands than farmers with lower number of livestock. Higher values of total grain products for poor households could be a reflection of the fact that better-off farmers allocate relatively more land to private grazing for livestock grazing than poor households. It could also be a reflection of price differences in the type of crops grown by farmers in different wealth categories.

Increasing LWP involves increasing the efficiency of feed utilization by the animals and increasing the efficiency of water use in feed production through improved rainwater management practices. Among the determinants of LWP, the positive relationship between family labour and LWP is plausible given that the bulk of labour for most farm operations in this region is provided by the family rather than by hired labour. Family labour takes great importance given that low income constrains hiring of wage labourers (Asfaw et al., 2011). The positive association of livestock holdings with LWP is a reflection of the high volume of beneficial outputs and services derived from ownership of large numbers of animals. The positive association of livestock holdings with LWP particularly relate to the fact that livestock provide replacement oxen which allow timely preparation of land for crop production. Livestock also provide manure for soil fertility replenishment (Herrero *et al.*, 2013). The positive association of individual households' livestock ownership with LWP suggests that farmers with fewer animals are at a disadvantage and that increased numbers of livestock will thus most likely lead to greater livestock water productivity in the short term. However, there is a limit: keeping large numbers of animals on limited natural resource base will result in overexploitation of natural resources through excessive removal of vegetation through grazing. Likewise, allocation of higher amounts of crop residue to livestock feed exerts a competitive pressure on alternative uses of crop residues such as for soil mulching, roofing and fuel (Giller et al., 2011b; Williams et al., 2000). Alternatively, high volumes of beneficial outputs and services can be achieved by keeping few productive animals, improved feeding and better health care. Therefore, it is important that strategies to improve LWP focus on sustainable intensification of crop-livestock production systems. Sustainable intensification implies that greater production must be achieved by increasing yields of a few animals while using fewer resources.

An increase in the age of household head was negatively associated with LWP. The negative association of increasing age with LWP supports our research hypothesis that older farmers may not have the physical strength to implement labour intensive farm operations that would increase productivity. Contrary to expectations, the size of land holding was negatively associated with LWP. A possible explanation for negative association of land holding size with LWP might be that large farms had to spread limited resources thinly to a large area of land, which led to less efficient use of water management practices. The insignificant coefficients for wealth category suggest that controlling for land and livestock holdings that are strongly correlated with wealth status of the household head, wealth category alone has no independent effects on LWP.

The positive relationship between LWP and livestock holding suggest that water use efficiency in livestock production can be achieved by increasing livestock beneficial outputs. The positive association of farm labour with LWP and the negative association of land holding size with LWP suggest that strategies for improving water use efficiency in production of livestock need to pay attention to the use of land saving and labour intensive agricultural technologies. The results suggest that water use efficiency can be improved by alleviating resource constraints such as access to farm labour and livestock assets, oxen in particular. The findings of this research help in making decisions about where to invest scarce resources to improve water use efficiency in livestock production under rain-fed conditions.

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Chapter 3

Characterisation of adopters and non-adopters of dairy technologies in Ethiopia and Kenya

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Abstract

While there is a general consensus that using dairy technologies, such as improved breeds of dairy cows, can substantially increase farm productivity and income, adoption of such technologies has been generally low in developing countries. The underlying reasons for non-adoption of beneficial technologies in the dairy sector are not fully understood. In this study, we characterised adopters and non-adopters of dairy technologies in Ethiopia and Kenya based on farmers' resources ownership in order to identify why many farmers in Ethiopia and Kenya have not adopted improved dairy technologies. As compared to non-adopters, farmers who adopt dairy technology own relatively more farm resources. The result signals that differences in resource endowments could lead to divergent technology adoption scenarios. Results show that a higher proportion of sample smallholders in Kenya have adopted dairy technologies than those in Ethiopia. Except for the use of veterinary services, fewer than 10 percent of sample farmers in Ethiopia have adopted dairy technologies-less than half the number of adopters in Kenya. The higher level of dairy technology adoption in Kenya can be ascribed partly to the long history of dairy development, including improvements in the value chain for the delivery of inputs, services and fluid milk marketing. Interventions that deal with the constraints related to access to farm resources and inputs and output markets could facilitate uptake of dairy technology in developing countries.

3.1. Introduction

Agricultural technologies, such as improved breeds of dairy cows and improved forages, have the potential to improve the livelihoods of smallholders through higher yields, better household income and improved nutrition. In the past 60 years, modern technologies in animal breeding, feeding and animal health care have been promoted to transform subsistence dairy production into market-oriented dairy enterprise in developing countries such as Ethiopia and Kenya (Duncan et al., 2013; Oosting et al., 2011; Staal et al., 2008). Despite many years of efforts, however, these technologies (e.g., improved breeds of dairy cattle, artificial insemination, improved forages and veterinary health care) are not commonly used by smallholders and the productivity of dairy cows remains low (Ayele et al., 2012; Duncan et al., 2013). Farmers that use technologies, however, have achieved average daily milk yields of 15 litres per cow in Ethiopia and Kenya, whereas farmers that have not use technologies have an average daily milk yield of 5 litres per cow (Asfaw et al., 2011; Staal et al., 2008; Tegegne et al., 2013; Wambugu et al., 2011). The question remains as to why only a small fraction of farmers take advantage of technologies in the dairy sector, while most farmers in similar agro-ecological regions and farming systems fail to do so. Where is that gap coming from?

One reason for differences in technology use among smallholders in developing countries could be differences in farmers' access to farm resources, technological inputs and differences in access to output markets (Mather et al., 2013; Wani et al., 2014). Past research findings also show that farmers are averse to risks associated with adopting technologies. They may not have the cash to finance adoption of technologies or safeguard financial losses (Abdulai and Huffman, 2005; Feder et al., 1985). Following these notions, some studies have analysed factors that affect adoption of dairy technologies by smallholders (Franzel et al., 2001; Staal et al., 2002; Tefera et al., 2014). These studies, however, assessed only the average adoption behaviour of smallholders, without considering heterogeneity between adopters and non-adopters of dairy technology in terms of access to farm resources, technological input and output markets. Very little systematic research has been conducted on the comparative analysis of the key differences between adopters and non-adopters of dairy technologies in developing countries.

To understand the constraints to technology adoption by smallholders in the dairy sector, we examined the heterogeneity in access to farm resources, technological inputs and in access to markets between adopters and non-adopters of dairy technologies. Identification of the constraints could help design targeted interventions that alleviate the constraints and take advantage of the opportunities. Moreover, distinguishing the heterogeneity between adopters and non-adopters of dairy technologies is particularly important for targeting and scaling up of dairy development interventions.

3.2. Material and Methods

3.2.1. Description of dairy technologies

Ethiopia and Kenya were selected as case study countries because these two countries represent a range of production resource settings, history and policy environments related to dairy development in East Africa. While Kenya is held up as an example of 'successful' dairy development in East Africa, Ethiopia is considered as having an underdeveloped dairy sector (Staal et al., 2008). The major efforts towards dairy development in the two countries have been focused on generation and dissemination of dairy technologies, including improved breeds of dairy cows, improved forages and animal health interventions (Ahmed et al., 2004; Spielman et al., 2010; Staal et al., 1997). Dairy cooperatives have also been promoted to enhance farmers' access to markets (Bernard and Spielman, 2009; Staal et al., 2008). Many of these technological and institutional interventions have been promoted in the two countries by agricultural extension for many years. In the present study, we defined dairy technologies broadly as a set of five technological inputs in dairy: improved dairy cows, artificial insemination (AI), improved forages, animal health care and milk marketing cooperatives. Brief descriptions of these dairy technologies are given below.

Improved dairy cows: Initial efforts on dairy development in Ethiopia were based on the introduction of high yielding exotic cattle in the highlands (Ayenew et al., 2011; Staal et al., 1997). Various government programs and several projects implemented by non-governmental organisations(NGOs) distributed exotic dairy cattle (Ahmed et al., 2004; Staal, 1995). Exotic dairy cattle breeds (*Bos taurus*) were introduced to the highlands of Kenya in 1920s (Staal, 1995). Crossbreeding or breed substitution has been promoted as a method of increasing animal productivity by the Ethiopian government and its development partners since early 1960's. Hence, ownership of improved dairy cows is considered as an important indicator of dairy technology adoption in these two countries.

Artificial insemination (AI): Reproductive technologies play an important role in genetic improvement programs. Generally, animal breeding programs aim to increase dairy productivity through breeding and selection implemented by using AI and bull services. The use of AI enables the production of a very large number of offspring from a single elite sire (Philipsson, 2000; van Arendonk, 2011). In Ethiopia and Kenya, AI has been widely promoted as an effective technique for dissemination of genetic gain to producers at a relatively low cost. The use of AI by individual farmers, therefore, can be considered as an indicator of dairy technology adoption.

Improved forage technologies: In market-oriented dairy farming in Ethiopia and Kenya, feed costs determine the majority of the cost price of milk production (Muriuki and Thorpe, 2006). Inadequate quantity and poor quality of feed, therefore, is one of the major constraints to increase livestock productivity in mixed crop–livestock systems (Ayele et al., 2012). . Natural pastures and crop residues, as the two most important feed resources, are unable to meet the nutrient requirements for milk production and reproduction. This has necessitated the growing and feeding of improved forages (Lenné and Wood, 2004; Mpairwe et al., 2003; Thomas and Sumberg, 1995). The use of cultivated fodder such as Napier grass, forage legumes and multipurpose trees by the small householders is considered as an indicator of adoption of feed technologies/interventions in this study.

Animal healthcare: Major health problems faced by dairy farmers in Ethiopia and Kenya include tick-borne diseases, which cause significant losses to livestock keepers (Asmare et al., 2013; Kang'ethe et al., 2012). Preventive measures involve spraying or dipping of animals using *acaricides*. In case of infection, appropriate drugs are given to the animals. The use of any veterinary services or drug by the sample household is considered as an indicator of adoption of veterinary related technologies.

Milk marketing cooperatives: Milk marketing is a major problem in rural areas due to distance from consumption centres and poor infrastructure. Dairy cooperatives help to overcome marketing constraints in rural areas (Jaleta et al., 2013; Owango et al., 1998). Dairy cooperatives play a role in collecting and bulking, transporting and selling milk on behalf of the members. Therefore, farmers' involvement in dairy cooperatives and selling their milk to cooperatives is considered as an indicator of the adoption of market related technologies.

3.2.2. Survey design and data collection

This study is based on two datasets collected in Ethiopia and Kenya to identify characteristics which distinguish adopters of dairy technologies from non-adopters. For both countries, data collected through household survey were supplemented by information from literature and relevant databases, such as FAOSTAT (FAOSTAT, 2014).

(a) Ethiopia

In Ethiopia, data were collected from 669 randomly selected households in seven districts (Jeldu, Guder, Shambu, Diga, Farta, Gondar Zuria and Fogera) during June-July, 2012. The seven districts were selected based on representativeness of the mixed crop-livestock farming system and suitability for dairy production. The data were collected through questionnaire interviews with the household head or in his/her absence, the most senior member available in the household. The variables of interest included information on household demographic characteristics, household farm resources and household assets, inventory of crop and livestock production activities, use of modern livestock technologies and practices, dairy production and marketing practices, household participation in dairy cooperatives, household access to credit and extension services and the distance a household is located from input and output markets.

(b) Kenya

In Kenya, comparable data were collected as a baseline for the East Africa Dairy Development Project (EADD) in 2009 (Baltenweck et al., 2011). The project sites were selected using GIS maps based on two indicators: climatic characteristics and distance to urban centre (as an indicator of market access). Based on these two indicators, five project sites (Kabiyet, Kaptumo, Soy, Siongiroi and Metkei) were selected for the survey in Kenya. Sample households were selected from each of the project sites for the interview with 525 farmers. The survey questionnaire used in Kenya was comparable with the questionnaire used in Ethiopia. The questionnaire was divided into different modules covering: household composition and labour availability, farm resources and household assets, inventory of crop and livestock activities, livestock management and health services, dairy production and marketing practises, use of modern technologies and practices, access to credit and extension services, and membership of co-operative and social networks. The details of data collection in Kenya are given in Baltenweck et al. (2011).

3.2.3. Description of factors affecting adoption of dairy technologies

Farmers' decisions to adopt agricultural technologies can be explained by factors that influence the expected benefits from the technology. Such factors can be broadly categorised into four major groups: technology attributes, farmers' attributes, farmers' resources and policy and institutional environment (Banerjee et al., 2014; Spiertz and Ewert, 2009; Staal et al., 2002). A number of variables which represent the above factors were used from the household surveys in Ethiopia and Kenya. The key explanatory variables included in the analysis and their hypothesised influence on adoption of dairy technologies is described below.

Age: Young household heads are more likely to apply new technologies because younger household heads are less risk averse than older counterparts (He et al., 2007; Sidibé, 2005). Thus we expect that younger household heads will be more likely to adopt dairy technologies.

Gender: Women play a significant role in dairy production in Ethiopia and Kenya. Most activities in dairy production such as cattle feeding, barn cleaning, calf rearing, milk handling and marketing are performed by women (Tangka et al., 1999; Yisehak, 2008). Therefore, the gender of household head being male could be associated negatively with the adoption of a dairy technology package.

Education: Education level is expected to have a positive influence on adoption of dairy technologies because of the assumed link between education and knowledge and the ability to read technical materials (Knowler and Bradshaw, 2007).

Family size: Family labour is the major source of labour for farm activities. Households with a large active workforce have the capacity to relax the labour constraints required for a labour intensive dairy enterprise (Shiferaw and Holden, 1998). Therefore, a larger active workforce is expected to affect the decision of adopting dairy technologies positively.

Dependency ratio: The dependency ratio within the household may reduce labour availability (Zezza et al., 2011). The dependency ratio relates the number of children (0-14 years old) and older persons (65 years or over) to the family members in working age group (15-64 years of age) (United Nations, 2007). Therefore dependency ratio is expected to be negatively associated with technology adoption.

Total land holdings: Larger land holdings are associated with greater wealth and increased availability of capital. Farmers with larger land holdings are more likely to invest in technologies that increase agricultural productivity and income (Jayne et al., 2010). For example, farmers with larger farm size could allocate part of their land for intensive fodder production (Staal et al., 2002). Therefore, farm size is hypothesised to have a positive association with adoption of improved dairy technologies.

Livestock ownership: The high population to land ratio results in scarcity of land and diminished grazing land, unable to maintain large number of livestock holdings. As a result farmers are expected to reduce the number of low yielding animals and keep few productive animals suitable for production of marketable outputs such as milk (Moll et al., 2007). Therefore, adoption of improved dairy cow technologies is expected to be negatively associated with large size of livestock ownership (Upton, 2000).

Oxen ownership: Oxen play a vital role in crop production and income generation in the Ethiopian highlands (Gebru, 2001). Higher income generated from crop production can be invested in intensive dairy enterprise. Therefore, oxen ownership is expected to have a positive association with adoption of dairy technologies.

Access to extension service: Distance to Farmer Training Centres (FTC) was used a proxy for access to extension service in Ethiopia. The FTCs are extension hubs in Ethiopia. Farmers living closer to FTC are expected to be more likely to know and meet an extension agent frequently. Therefore, we expect distance to the nearest FTC to have a negative effect on the adoption of dairy technologies. Farmers' response to the question regarding to contact with extension workers was considered as an indicator of access to extension service in Kenya. Diffusion of new technologies may also be influenced by the visits agricultural extension agents pay to the farmers. Frequent meetings with extension agents promote knowledge flows about new technologies and services.

Distance to the nearest market centre: Households should be integrated with input and output markets to reap benefits from dairy technologies. Indicators of physical access to infrastructure are good proxies for institutional conditions that also shape market access conditions (Duncan et al., 2013; Kruseman et al., 2006). We expect that farmers located in remote areas with poorer transportation infrastructure will suffer from less favourable input-output price ratios, fewer local trading opportunities, and less competitive local marketing conditions. Therefore, we expect distance to the nearest market centre to have a negative influence on the adoption of dairy technologies.

Access to mobile telephone: Access to mobile telephone is important for technology adoption decision due to the importance of information on technology adoption in general and the fact that dairy farming is an information intensive enterprise in particular (Aker, 2011; Pannell et al., 2006). Ownership of mobile phones offers an opportunity to get information about dairy technologies and market information. Mobile telephone can link farmers and input providers, as well as farmers and buyers. Therefore, we expected farmers who own a mobile telephone are more likely to adopt dairy technologies. We also suspect access to mobile telephone may have two way causal relationships with adoption of dairy technologies. Logically, better off farmers have financial resources needed to purchase mobile telephone. On the other hand, access to information about technology via mobile telephone could facilitate adoption of technologies and attainment of better income.

Occupation diversity: There is increasing evidence that engagement in off farm occupations contributes to household income in developing countries (Bezu et al., 2012; Reardon et al., 2000). Often households enjoy high rates of return on their human and physical capital investment in off farm activities (Bezu et al., 2012). Therefore, farmers engaged in diverse off farm occupations are expected to be less likely to invest their resources in dairy technologies unless the rate of return from dairy sector is substantially higher than the ones obtained from competing economic activities.

Access to credit: New agricultural technologies require a significant capital investment. Smallholder farmers may not have adequate financial capital to invest in agricultural technologies. Many farmers have difficulty accessing credit and face high interest rates, which prevents investment in profitable technologies (Abdulai and Huffman, 2005). Therefore, we expect farmers who have better access to credit to be more likely to adopt dairy technologies.

3.2.4. Statistical analysis

A chi-square test was used to assess if there was a difference between adopters and non-adopters of dairy technologies in farm resource endowment and access to inputs and output markets (Liski, 2007). Similarly, chi-square test was used to test the differences in the proportions of binary response variables for adoption of the five dairy technologies. Correlation analysis was used to study associations between adoption of various dairy technologies (Rabe-Hesketh and Everitt, 2007). The correlation between adoption of technologies tests the adoption of dairy development interventions, such as AI service, improved forages, veterinary inputs and dairy cooperatives in each country.

3.3. Results

3.3.1. Adoption of dairy technologies in Kenya and Ethiopia

Results of statistical analysis in Table 1 show that farmers in Kenya have higher levels of adoption for all five technologies compared with farmers in Ethiopia. Relatively large numbers of sample households in Kenya keep improved dairy breeds (grade dairy cows or crosses of Holstein-Friesian breed), use AI, grow improved forages, use veterinary services

Table 1. Mean difference in adoption of major dairy technologies in Kenya and Ethiopia

Technologies	Kenya (n=525)	Ethiopia (n=668)	Diff	Chi-square statistics
Improved dairy breeds	0.51	0.04	0.47***	21.12
Artificial insemination services	0.13	0.03	0.10***	6.70
Improved forages	0.21	0.07	0.14***	6.78
Veterinary services	0.84	0.72	0.13***	4.69
Dairy cooperatives	0.07	0.01	0.06***	4.90

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

and participate in dairy cooperatives than the sample households in Ethiopia. Except for the use of veterinary services, fewer than 10 percent of sample farmers in Ethiopia have adopted dairy technologies-less than half the number of adopters in Kenya.

Table 2 shows the correlations between adoption among five technologies in Ethiopia. Positive correlations were found among improved dairy cows and AI services, improved dairy cows and improved forages, improved dairy cows and dairy cooperatives, AI services and improved forages, AI services and veterinary services and improved forages and veterinary services in Ethiopia.

Table 2. Correlations between selected dairy technologies in Ethiopia

	Improved cows	Artificial insemination	Improved forages	Veterinary services
Improved cows				
Artificial insemination	0.59***			
Improved forages	0.11***	0.13***		
Veterinary services	0.06	0.06***	0.09	
Dairy cooperatives	0.09**	0.13***	0.06	-0.03

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

In Kenya, adoption of improved dairy cows was positively correlated with adoption of AI services, improved forages and veterinary services (Table 3). Moreover, adoption of AI services was positively correlated with adoption of improved forages, veterinary services and dairy cooperatives. Adoption of improved forages was also positively correlated with adoption of veterinary services and dairy cooperatives (see Table 3).

Table 3. Correlations between selected dairy technologies in Kenya

	Improved cows	Artificial insemination	Improved forages	Veterinary services
Improved cows				
Artificial insemination	0.10***			
Improved forages	0.26***	0.23***		
Veterinary services	0.41***	0.21***	0.29***	
Dairy cooperatives	0.05	0.09***	0.09***	0.22***

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

3.3.2. Smallholder farmers' access to farm resources

The differences between adopters and non-adopters of improved dairy technologies in access to farm resources are presented in Tables 4 and 5. In Ethiopia, adopters of improved dairy cows had a higher number of family members in working age group (15-64 years of aged), low number of dependants (aged under 15 and over 65 years). Adopters also had better access to mobile telephone than non-adopters. Adopters of AI services had a higher number of family members in working age group, better access to mobile telephone, and reside far away from the nearest market centre and farmer training centre than non-adopters. Adopters of improved forages were mainly male headed, had higher access to mobile telephone and reside close to the nearest market centre and farmer training centre than non-adopters. Adopters of veterinary services had more female headed and unmarried household heads with higher education levels and higher number of family members in working age group and better access to mobile telephone than non-adopters. Adopters of dairy cooperatives had relatively younger households with higher education levels and reside close to the nearest market centre than non-adopters. Contrary to expectations, there was no difference between adopters and non-adopters of improved dairy technologies in the size of land, livestock and oxen holdings. Adopters and non-adopters of improved dairy technologies were indistinguishable in terms of access to agricultural credit and access to extension services.

Generally, farmers who adopted many of the dairy technologies had relatively higher number family labour and better access to mobile telephone than non-adopters in Ethiopia. In Kenya, adopters of improved dairy cows had higher livestock assets, better access to

Table 4. Mean differences in key farm resources between adopters and non-adopters of improved dairy technologies in Ethiopia

Variables	Mean difference between adopters and non-adopters of technologies				
	Improved cows	AI services	Improved forages	Veterinary services	Dairy cooperatives
Age of household head (y)	5.16	3.28	0.54	-1.34***	-10.33**
Gender of household head (1=male)	0.023	-0.01	0.15***	0.09	0.16
Marital status of household head (1=married)	0.03	0.00	0.09	0.08***	0.06
Education level of household head (y)	-0.11	0.16	-0.36	-0.55***	-1.42**
Number of family members in working age group	1.60***	1.73***	0.50*	0.75***	-0.81
Dependency ratio	-0.32**	-0.31	-0.02	0.07	0.08
Total land holding (ha)	-0.53	-0.05	-0.55	0.07	-0.74
Total livestock holding (TLU[1])	0.54	1.91*	0.03	-0.23	1.56
Oxen holding (TLU)	0.42	0.46	0.06	0.00	0.79
Access to mobile telephone (1=yes)	0.37***	0.38***	0.22***	0.14***	0.15
Distance to nearest market centre (km)	-0.79	-3.45*	2.67**	0.89	-6.34**
Distance to Farmer Training Centre (km)	-1.33	21.95***	7.08***	0.73	-1.36
N	658	658	658	658	657

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

[1]TLU= Tropical livestock unit using a conversion factor of a mature animal weighing 250 kg (ILCA, 1990).

mobile telephone and less diverse livelihood activities (farmers having part-time employment, small-scale businesses in village towns, etc.) than non-adopters. Adopters of AI services had relatively older household heads, less number of dependants and better access to mobile telephone than non-adopters. Adopters of improved forages had household heads with relatively better education level and better access to mobile telephone than non-adopters. Adopters of veterinary services had male household headed with relatively higher education level, higher family size and land holding, better access to mobile telephone and extension services, and reside relatively far away from milk selling point than non-adopters.

Table 5. Mean differences in key farm resources between adopters and non-adopters of improved dairy technologies in Kenya

Variables	Mean difference between adopters and non-adopters of technologies				
	Improved cows	AI services	Improved forages	Veterinary services	Dairy cooperatives
Age of household head (y)	0.23	5.36**	0.12	2.05	-2.18
Gender of household head (1=male)	-0.012	-0.03	0.05	0.13**	0.11**
Education level of household head (y)	-0.26	0.93	1.44***	1.84***	2.33***
Family size in adult equivalent	-0.27	0.31	0.38	1.34***	-0.33
Dependency ratio	-4.58	-31.77***	-4.82	6.31	3.12
Total land holding (ha)	1.06	-0.96	-1.05	3.19***	-1.63*
Total livestock holding (TLU)	8.02***	1.28	0.61	0.07	-5.39***
Access to mobile telephone (1=yes)	0.48***	0.18***	0.12**	0.20***	0.11
Occupation diversity (1 to 4 types)	-0.52**	0.29	0.54	0.54*	0.12
If household received loan (1=yes)	0.01	-0.06*	0.01	0.01	-0.02
Access to extension service (1=yes)	-0.07	0.10	0.07	0.66***	0.12
Distance to milk selling point (km)	-3.49	0.00	0.03	0.02**	-0.01
N	384	384	384	384	384

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

Adopters of dairy cooperatives had male household heads with relatively higher education level and higher livestock holdings than non-adopters.

3.4. Discussion

The focus of the present study was to gain insight into factors explaining differences in adoption rate of dairy technologies by smallholders in Ethiopia and Kenya. We determined the difference between smallholders who adopted dairy technologies and those who did not, in terms of demographic characteristics of households, households' access to farm resources and access to markets for technological inputs and services and output markets in Ethiopia and Kenya. Results show that a higher proportion of sample smallholders in Kenya have adopted improved dairy cows, and other complementary technologies (e.g. AI services, improved forages, participation in dairy cooperatives) than smallholders in Ethiopia. The positive correlation among adoption of the technologies is consistent with the expectation that dairy technologies explored in this study are interrelated.

In Ethiopia, the difference between adopters and non-adopters might be explained partly by the differences in number of family members in working age group and access to mobile telephones. Since dairy farming requires additional labour and capital, smallholders with limited ownership of these resources are less likely to investment in dairy technologies. The result on access to mobile telephone was very consistent across both countries. Higher level mobile telephone ownership by adopters of dairy technologies in Ethiopia and Kenya suggests that mobile telephones could facilitate technology adoption by improving access to information about different aspects of the technologies and market. Farmers need information about the presence of a technology, its benefits and how to use it effectively before adopting it. Smallholder farmers often find it difficult to obtain such information locally. Ownership of mobile telephones could improve access to market information and help farmers gain better insights about different aspects of the technologies.

The differences in livestock holdings between adopters and non-adopters of improved dairy cows in Kenya suggest that access to fixed assets could be important determinants of dairy technology use. Although land is one of the key farm resources, we could not find clear difference in the size of land holding between adopters and non-adopters of dairy technologies. Mobile telephone could be considered as an important physical asset in African context. Therefore, the difference in ownership of mobile telephone could be interpreted as proxy indicator of differences in wealth between adopters and non-adopters, besides its use as a means to access information. Given that livestock development programs rely on extension workers for veterinary services, the increase in the use of veterinary services with increasing access to extension services in Kenya appears reasonable.

The result indicates that productive resources ownership partly explains as to why few farmers adopt technologies while the majority of smallholders are unable to do so. The results support the claim that persistent lack of dairy technology adoption is a reflection of the differences in access to farm resources (Collier and Dercon, 2013). However, access to farm resources and individual choice alone may not fully explain the differences in adoption. The reason for the generally low level of dairy technology adoption in both countries could also be explained by factors rooted in access to markets and higher level policy context that govern production relations in smallholder agricultural systems (Barrett et al., 2010; Birner and Resnick, 2010).

The low level of dairy technology adoption in Ethiopia could partly be attributed to missing input supply. The supply of replacement heifers and provision of veterinary service and artificial insemination in Ethiopia is inadequate and underdeveloped (Ayele et al., 2012; Jaleta et al., 2013; Tegegne et al., 2010). In Ethiopia, markets for dairy products are very thin and own-consumption shares are very high (Duncan et al., 2013; Hoddinott et al., 2014). The lack of a reliable markets and poor road infrastructure could exacerbate the challenges in the value chain (Seyoum, 2014). The value chain for collecting, cooling, processing and marketing of milk and milk products is not well developed (Francesconi and Heerink, 2011). Only a small proportion of fluid milk produced by smallholders is collected, packed and sold to consumers by dairy processing plants and marketing enterprises. Rural dairy farmers have very little access to urban fluid milk markets and milk is often processed into butter. The higher proportion of milk produced by smallholder farmers is marketed through both informal and formal marketing systems. In informal marketing systems, producers sell to the neighbours, small restaurants or to unlicensed retailers. The major dairy products commonly marketed in rural areas include *ergo* (fermented whole milk), local butter, butter milk and cottage cheese (Tegegne et al., 2013). The role of dairy cooperatives in milk marketing is also very limited in terms of volume and coverage (Francesconi and Heerink, 2011).

One plausible reason for the difference in dairy technology adoption levels in the two countries could be due to variation in the institutional environment rather than just the small differences in farmers' resource endowments. The higher level of dairy technology adoption in Kenya could be ascribed to the long history of a well-developed value chain for the delivery of inputs, services and fluid milk in Kenya. Kenya is one of the largest producers of dairy products in Africa, with the highest per capita consumption of milk in Africa, estimated at four times the Sub Saharan African average of 25 kg (Muriuki and Thorpe, 2006). Kenya has a long history of a well-developed value chain for fluid milk (Staal et al., 2008). In Kenya, about 55 % of the milk produced by farmers enters the market. Supermarkets and farmer organisations play an important role in linking smallholders to emerging food value chains (Poulton et al., 2010). There are about 30 licensed milk processors. Brookside and Kenya Cooperative Creameries alone process more than 60 % of the total processed milk (Muriuki, 2011). Cooperatives and farmers' groups handle about 40 % of marketed milk production and about 20 % of total milk (Muriuki, 2011). Supermarkets in Kenya have grown from a tiny niche market only 7 years ago to 20 % of urban food retail in 2010. The difference in dairy technology adoption trajectories between sample households in the two countries could be attributed to differences in socio-economic and policy environment between Ethiopia and Kenya. Technology purchase and use could be limited by weak supply chains, missing infrastructure (e.g. roads or electricity) and uncertain property rights (Barrett et al., 2010; Demeter et al., 2009). Therefore, economic, institutional, political and cultural barriers could influence the extent to which farmers adopt beneficial technologies.

The difference between adopters and non-adopters of dairy technologies presented in preceding sections has important policy implications. Interventions that overcome the constraints related to access to farm resources and the supply chain for technological inputs and services and output markets could facilitate uptake of dairy technologies. Market access constraints could be alleviate through infrastructure improvements and targeted institutional arrangements for distribution of technological inputs and services could improve technology adoption and productivity of dairy. For farmers constrained by market access, the focus of intervention needs to be on facilitating market linkages (for example through an integrated dairy hub model), improving services, product value addition and increasing scale of production. Lastly, there is a need for the shift of research focus towards exploring alternative ways of promoting technology dissemination instead of generating additional technical innovations and pushing them through the conventional extension system.

In summary, this study examined adoption of dairy technologies by smallholder farmers in Ethiopia and Kenya. The results show that Kenya has relatively more farmers using improved dairy cows, AI services, improved forages and participating in dairy cooperatives than farmers in Ethiopia. On aggregate, adoption of improved dairy technologies and husbandry practices has been below 10 % in Ethiopia. The current agricultural research and extension approach, despite all the best efforts, appears to be unsuccessful in diffusion of dairy technologies. Farmers who use dairy technologies have better resource endowments and better access to value chains for complementary inputs, services and output markets as compared to non-users of dairy technologies. In Ethiopia, adopters and non-adopters differed in terms of availability of family labour and access to mobile telephone. In Kenya, differences were observed between users and non-users of dairy technology in livestock holdings and access to mobile telephone. Given the limited resource endowment and the constraints in the value chain, majority of smallholders have insufficient economic incentives to adopt dairy technologies.

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Chapter 4

Impact of dairy technology adoption on household nutrition and income in Ethiopian highlands

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Abstract

This paper investigated the impact of adopting dairy technologies on household nutrition and income using propensity score matching and a sample treatment effect estimator. Results show that adopting crossbred dairy cows and improved forages increased household nutrition status and income. The comparison of adoption impact estimates by propensity score matching and the sample treatment effect estimator indicated that unobservable variables have influence on technology adoption and impacts, which suggests that smallholders are heterogeneous in initial resource ownership conditions and in individual characteristics such as entrepreneurial ability, motivation or ingenuity, attitude towards risk and networking ability. The variation in such initial resource ownership status and in individual characteristics may explain part of the variation in adoption of dairy technologies and their impacts.

4.1. Introduction

Intensification of dairy production through the use of agricultural technologies is widely advocated in developing countries, both to meet increasing demand for milk products and to contribute to the development of households (Delgado et al., 2001; McDermott et al., 2010; Staal et al., 2008; Udo et al., 2011). Crossbred dairy cows and improved forages have the potential to improve the welfare of farmers through higher milk yields, better income and improved nutrition. Several technological interventions have been promoted in Ethiopia to enhance the productivity of dairy cattle since the early 1960's. For example, crossing indigenous breeds of cattle with exotic breeds of dairy cows has been extensively promoted as a promising option to enhance the productivity of dairy cattle in Ethiopia (Ahmed et al., 2004; Brotherstone and Goddard, 2005; Rege et al., 2011). Several organizations have also promoted improved forages in Ethiopia since the 1970s (Duncan et al., 2013; Mekoya et al., 2008; Ran et al., 2013). Despite many research and extension efforts, these technologies have not been adopted by most Ethiopian smallholders and livestock productivity remains very low (Ayele et al., 2012; Duncan et al., 2013). The problem of low technological adoption in Ethiopia is not primarily one of lack of technologies, for technologies that could increase the productivity of dairy animals are available. The notion that technologies have different benefits to different groups of farmers could explain why not many Ethiopian smallholders have adopted them (Fischer and Qaim, 2012; Suri, 2011). Suri (2011) argues that one cannot assume a profitable technology for one farmer will be profitable for every farmer as welfare effects of technology adoption could be insignificant or negative to certain groups of farmers.

Increased household nutrition and income are the two important impact pathways through which adoption of dairy technologies is expected to contribute to smallholder livelihoods enhancement. Malnutrition remains a major and persistent problem in the developing world (Godfray et al., 2010; Randolph et al., 2007). Availability of affordable food of animal origin would contribute to alleviating malnutrition. Consumption of dairy products usually has a positive effect on human nutrition and health (Ahmed et al., 2000; Kristjanson et al., 2004; Randolph et al., 2007).

However, the question of whether adopters and non-adopters of dairy technologies have inherent differences in welfare outcome potentials is an area where relatively little research has been done. More specifically, the question as to how human nutrition status has changed in response to adoption of dairy technologies in developing countries has largely remained unexplored. Assessing the benefits of dairy technologies to smallholders with respect to their impacts on household nutrition and income could provide important insights into the potential contribution of dairy technologies to household welfare enhancement (Baltenweck et al., 2011; Kristjanson et al., 2007; Marshall, 2014; Mohamed et al., 2002; Udo et al., 2011). The role of livestock intensification on the livelihoods of poor livestock keepers was assessed by Kristjanson et al. (2007). They used a binary logistic regression to examine the role of livestock on household poverty dynamics. Their model, however, compared only the average welfare effect of dairy technology interventions between adopters and non-adopters, with no consideration of unobservable differences between households. Another important empirical study on the impact of dairy intensification on household welfare was by Ahmed et al. (2000). This study analysed the impact of introducing crossbred cows and improved forages on household income and caloric intake using a simultaneous regression model. Ahmed et al. (2000) used a pooled model estimation technique which assumes that the set of adoption determinants have the same impact on adopters and non-adopters. Their model did not account for differences in welfare outcomes between adopters and non-adopters of improved dairy technologies that arise due to unobservable differences between agricultural households. This is inappropriate in contexts where farmers have observable differences (e.g., in resources and market access) and unobservable differences (e.g., entrepreneurial ability, farmers' motivation or ingenuity, risk preferences and networking ability). Not distinguishing the causal effect of adopting dairy technologies and the effect of unobservable differences could lead to misleading conclusions (Blundell and Dias, 2002; Dutoit, 2007; Heckman et al., 2001). Effective impact evaluation methods discern the mechanisms by which the beneficiaries are responding to the interventions (Heckman et al., 2001).

This paper explores whether adopting dairy technologies significantly influences welfare outcomes in rural Ethiopia. Specifically, we test whether adopting dairy technology interventions has an impact on household nutrition status and income for adopters and whether adopting dairy technologies would have an impact on household nutrition status and income for non-adopters if they decided to adopt the technologies. We assess the impacts of dairy technology adoption on household welfare in two specific ways. First, we analyse dairy technology effects on household nutrition and income using propensity score matching (Rosenbaum and Rubin, 1983). Second, we check the robustness of propensity score matching estimates using a sample treatment effect estimator based on a subsample of the original dataset that is more balanced in the covariates (Abadie and Imbens, 2006; Imbens, 2004).

4.2. Dairy farming and technology use in Ethiopia

In rural areas, where land size is shrinking and malnutrition is widespread, introduction and intensification of dairy cows is often considered as an important strategy to realize greater supply of dairy products and income to rural households. This is particularly important in areas where dairy product markets are either thin or missing, which is typically the case in many rural areas of Ethiopia. The dairy sector in the Ethiopian highlands is, however, characterised by a dominance of smallholders farmers keeping indigenous cattle of low productivity, subsistence-oriented production, scant use of technological inputs and underdeveloped markets for inputs, services and outputs (Ahmed et al., 2004). As mentioned above, several technologies have been promoted in Ethiopia to enhance the productivity of dairy cattle since the early 1960's. The major efforts of dairy development in Ethiopia in the last 60 years have been focused on generation and dissemination of a number of dairy technologies including improved breeds of dairy cows and improved forages (Ahmed et al., 2004; Spielman et al., 2010; Staal et al., 1997). Due to their relative importance to the success of improved dairy production, we consider adoption of crossbred dairy cows and improved forages as the two important dairy development interventions for this study.

Crossbred dairy cows: The beginning of modern dairying in Ethiopia dates back to early 1950's when Ethiopia received the first batch of dairy cattle from the United Nations Relief and Rehabilitation Administration (Staal and Shapiro, 1996). This was followed by a series of government and donor assisted dairy development programs and projects. Initial efforts on dairy development were based on the introduction of high yielding cattle in the highlands (Ayenew et al., 2011; Ketema, 2000). Crossbreeding has been viewed as a method of increasing animal productivity by the Ethiopian government and its development partners since early 1960’s. Various government programs and several projects have distributed dairy cattle (Ahmed et al., 2004; Staal, 1995). Hence, ownership of crossbred dairy cows is considered an important indicator of dairy technology adoption.

Improved forages: Feeds account for the largest share of the cost of milk production in dairy farming in Ethiopia. Poor quality of feeds and the overall scarcity of feed are major constraints to livestock production in mixed crop–livestock farming systems (Ayele et al., 2012). To alleviate the shortage of livestock feed, improved forage technologies such as planted fodder crops, multipurpose trees, pasture improvement and management, feed conservation technologies and the use of agro-industrial by-products have been promoted (Lenné and Wood, 2004; Mpairwe et al., 2003; Thomas and Sumberg, 1995). Therefore, the use of cultivated fodder such as elephant grass, oats-vetch, forage legumes and multipurpose trees by small agricultural households is considered as adoption of improved forage technologies in this study.

4.3. Materials and Methods

4.3.1. Data collection

The data used for this study were derived from a farm-household survey conducted in seven districts (Jeldu, Guder, Shambu, Diga, Farta, Gondar Zuria and Fogera) in Ethiopia during June and July, 2012. The seven districts were selected purposively based on representativeness of the mixed crop-livestock farming system and suitability to dairy farming. A total of 669 farmers were included in the survey. The data were collected using a pre-tested structured questionnaire by trained enumerators with good knowledge of the farming systems and fluency in the local language. The questionnaire was completed through interviews with the household head or in his or her absence, the most senior household member available. The variables of interest included information on household demographic characteristics, household farm resources and household assets, an inventory of crop and livestock production activities, use of modern livestock technologies, dairy production and marketing practises, household participation in dairy cooperatives, household access to credit and extension services, the distance a household resides from input and output markets and household sources of income and expenditure. The questions on monthly expenditure, which is used as a proxy for measuring household cash income, were based on the template for the categories of goods and services in the Ethiopia Rural Household Survey questionnaire (Dercon and Hoddinott, 2004). The total monthly expenditure was computed by aggregating all expense categories (such as expenses for food items, clothes, school fees, weddings, funerals, loan repayment, membership fees to local organizations, and church donations,). The household dietary diversity score (HDDS) is increasingly used as measures of food security and as a proxy for nutrient adequacy in recent years (Beegle et al., 2012; Behnassi et al., 2013; Ruel, 2002; Swindale and Bilinsky, 2006; Thorne-Lyman et al., 2010). In the questionnaire we included questions regarding the number of food types or food groups consumed during the last seven days to estimate HDDS.

4.3.2. Household welfare indicators

In this study, household dietary divertiy score (HDDS) and income were used as household welfare indicators in the impact evaluation. The HDDS was used as an indicator of household nutrition status. The HDDS is defined as the number of food groups consumed during the last seven days (Keding et al., 2012; Swindale and Bilinsky, 2006) . The HDDS is a continuous score from 0 to 12. Food items were categorised into 12 different food groups with each food group counting toward the household score if a food item from the particular group was consumed by anyone in the household in the previous seven days. The food groups used to calculate the HDDS included: cereals, roots and tubers, vegetables, fruits, milk and milk products, meat, eggs, fish, pulses and nuts, oils and fats, sugar and condiments (Andrew et al., 2010; Jones et al., 2014; Snapp and Fisher, 2014; Swindale and Bilinsky, 2006; Thorne-Lyman et al., 2010). As Delgado *et al*. (2001) and Kristjanson *et al*. (2004) argued, income is the major impact pathway by which the use of crossbred cow technologies contributes to the livelihoods of livestock keepers. Higher incomes allow higher expenditure and thus greater food intake, indicating better access to food and improved nutrition. Consumption expenditure was used for impact analysis because expenditure data are considered more reliable than income data in rural settings in developing countries (Andrew et al., 2010; Ruel et al., 2004).

4.3.3. Statistical analyses

A chi-square test was used to assess the equality of means for continuous variables and equality of proportions for binary variables for adopters and non-adopters (Liski, 2007). We used propensity score matching (Rosenbaum and Rubin, 1983) and the sample treatment effect estimator (Abadie and Imbens, 2006; Imbens, 2004) to analyse the association between dairy technology adoption and impact of such technologies.

Propensity score matching: Propensity score matching (PSM) has been widely used to assess the impacts of technology adoption on household welfare (Abebaw and Haile, 2013; Girma and Gardebroek, 2015; Kabunga et al., 2014; Kassie et al., 2011; Rosenbaum and Rubin, 1983; Takahashi and Barrett, 2013). The PSM is defined as the conditional probability that a farmer adopts the new technology, given pre-adoption characteristics (Rosenbaum and Rubin, 1983). The basic idea behind matching is to find a group of non-participants (non-adopters in our case) who are similar to the participants (adopters) in all relevant pre-treatment characteristics (Rosenbaum and Rubin, 1983). Therefore, the first step in the application of PSM is to estimate the predicted probability that a household adopts a given dairy technology, also known as the propensity score. The PSM approach balances the observed distribution of covariates across the groups of adopters and non-adopters based on observables. Propensity scores estimated by a logit model were used to match non-adopters of crossbred dairy cows and improved forages to those that adopted these technologies. We included a vector of covariates related to agricultural household demographic characteristics and household asset ownership in the logit regression to estimate propensity scores.

The propensity score (Rosenbaum and Rubin, 1983), which is the probability of assignment to the treatment condition on pre-treatment variable can be expressed as:

$$p(Z) = Pr\{D = 1|Z\} = E\{D|Z\} \quad (1)$$

Where $D = \{0,1\}$ is the indicator for adoption and Z is the vector of pre-adoption characteristics. The conditional distribution of Z, given by $p(Z)$ is similar in both adopter and non-adopter groups.

Once the propensity score is computed, the population average treatment effect (ATE), the average treatment effect on the treated households (ATT) and the average treatment effect on untreated households (ATU) can be computed. The population average treatment effect (ATE) is the difference of the expected outcomes after adoption and non-adoption.

The population average treatment effect (ATE), which is simply the difference of the anticipated outcomes after adoption and non-adoption can be expressed thus:

$$\tau_{ATE} = E(\tau) = E[Y(1) - Y(0)] \tag{2}$$

Our main interest is on the impact of the treatment on the treated (ATT) on household nutrition and income. We were also interested in the average treatment effects of dairy technology adoption on the untreated (ATU) households to see the counterfactual impact of the technologies for non-adopters, had they decided to adopt the dairy technologies (Caliendo and Kopeinig, 2008). The ATT is defined as the difference between expected outcome values with and without treatment for those who actually participated in the treatment. Once the propensity score is computed, the average treatment effect on the treated (ATT) can be estimated as follows:

$$\tau_{ATT} = E\{Y_{1i} - Y_{0i}|D_i = 1\} = E[E\{Y_{1i} - Y_{0i}|D_i = 1, p(Z_i)\}]$$

$$= E[E\{Y_{1i}|D_i = 1, p(Z_i)\} - E\{Y_{0i}|D_i = 0, p(Z_i)\}|D_i = 1] \tag{3}$$

Where Y_1 and Y_0 are values of the outcome variable of interest for adopters and non-adopters, respectively; i refers to the agricultural household.

The fundamental evaluation problem arises because only one of the potential outcomes is observed for each individual i. The unobserved outcome is called the counterfactual outcome: what outcome the participants (treated units) would have had if they did not participate. Hence, estimating the individual treatment effect τ_{ATT} is not possible unless one circumvents the counterfactual outcome problem. We cannot observe how they would have performed had they not adopted the technologies, but we observe a corresponding outcome for the untreated. The PSM uses the observed outcomes of the untreated groups (non-adopters) as a counterfactual outcome of the participants (adopters in our case) to estimate the ATT (Rosenbaum and Rubin, 1983). Hence, the outcome values of the untreated (non-adopters) help us construct the counterfactual for the treated group and estimate the ATT (Caliendo and Kopeinig, 2008). The ATT in our case is the average effect of dairy technology adoption (i.e., adoption of crossbred dairy cows or improved forages) on agricultural household income and nutritional security.

The average treatment effects (ATE, ATT and ATU) were estimated using Kernel matching algorithm (Becerril and Abdulai, 2010). To estimate the average treatment effects, Kernel matching numerically derives a weighted average outcome of “neighbours” of non-adopters that have a propensity score that is close to the propensity score of the adopters (Becker and Caliendo, 2007). The treatment effects were estimated using the PSMATCH2 Stata module (Leuven and Sianesi, 2012).

The PSM method needs to satisfy some matching quality tests before considering the results to be valid for impact evaluation. The first step is checking the satisfaction of the two key assumptions of PSM with a set of observed covariates: the common support and balancing property assumptions. The first step in PSM estimation is assessing the common support (overlap in the covariate distributions) to ascertain fulfilment of the first assumption of PSM through visual inspection of the frequency distributions of the estimated propensity scores for the two groups. For ATT it is sufficient to ensure the existence of potential matches in the control group. The second step is to check whether the balancing property holds. The balancing property condition states that, conditional on the propensity score, the differences in the distributions of the covariates in the pools of treated and untreated units must be balanced (Caliendo and Kopeinig, 2008).

Rosenbaum sensitivity test: The PSM method assumes that observable covariates account for the selection process into the treatment and control individual’s conditions (un-confoundedness assumption). The main limitation of the PSM method is that if unobservable factors affect adoption decisions, the estimated ATT may be biased due to those unobservable factors (DiPrete and Gangl, 2004; Rosenbaum, 2002). Adopters and non-adopters could differ in unobservable characteristics. Examples of such unobservable variable are entrepreneurship, farmers' motivation or ingenuity, attitudes to risk and networking ability, all of which could affect both technology adoption and the outcomes of adoption (De Janvry et al., 2010; Hujer et al., 2004). Hence, sensitivity of estimated treatment effects with respect to unobservable factors could introduce hidden bias to the estimated treatment effects. The Rosenbaum sensitivity test was conducted to assess the plausibility of the un-confoundedness assumption (i.e. to test whether unobservable variables confounded the adoption effect) (Rosenbaum, 2002). The Rosenbaum sensitivity test relies on the sensitivity parameter Γ that measures the degree of departure from random assignment of treatment. Two subjects with the same observed characteristics may differ in the odds of receiving the treatment by at most a factor of Γ. In a randomized experiment, randomization of the treatment ensures that Γ=1. In an observational study, if Γ=2, and two subjects are identical on matched covariates then one might be twice as likely as the other to receive the treatment because they differ in terms of an unobservable covariate (Keele, 2010; Stangl, 2008). Based on that, bounds for significance levels and confidence intervals can be derived that provide information on potential impact of un-observable variables on the calculated treatment effects.

Sample treatment effect estimator: The propensity score matching method is basically built on the assumption of large sample properties (Abadie and Imbens, 2006; Imbens, 2004; Imbens, 2014). However, propensity score matching does not perform well in small samples in comparison with other estimators. The unconfoundedness assumption implies that all variables that influence treatment assignment and potential outcomes simultaneously have to be observed by the researcher. Clearly, this is a strong assumption. We had concerns that the available data were not rich enough to justify this assumption. As Abadie and Imbens (2006) show, some of the formal large sample properties of matching estimators may not satisfied when PSM is implemented in small samples. In settings with a low number of treatment cases relative the number of controls, the results of the PSM model could be sensitive to bias. In light of the emerging literature on these issues, we had concerns about the power of estimates from PSM in detecting treatment effects for the population because of the small number of treatment cases in our data. Therefore, we checked the robustness of PSM estimates using the sample treatment effect estimator based on a subsample of the original dataset that is more balanced in the covariates (Abadie et al., 2004; Abadie and Imbens, 2006; Imbens, 2004). In settings with low numbers of treated units relative to large numbers of controls, a consistent estimator for the variance of matching estimators was proposed by Abadie and Imbens (2006). The sample treatment effect estimator does not require consistent nonparametric estimation of unknown functions. The sample treatment effect estimator is robust to limited overlap of covariate distributions. The sample treatment effect estimator estimates the average treatment effect using nearest neighbour matching on the dependent variable by comparing outcomes between treated and control observations [details are given in Abadie *et al*. (2004)].

4.4. Results

4.4.1. Descriptive statistics

Mean values for adopters and non-adopters of crossbred dairy cows and improved forages were different with respect to HDDS, income, number of family members of working age, dependency ratios and ownership of a mobile telephone (Table 1). Compared to non-adopters of crossbred dairy cows, farmers who own crossbred dairy cows and have planted improved forages had a higher HDDS and income. Moreover, adopters and non-adopters of improved forages differed with respect to gender of household head, distance to nearest market centre and distance to farmers' training centre.

The average mean difference in outcome variables presented in Table 1 may mask the actual differences between adopters and non-adopters because of the effect of unobservable variables. For example, when adoption of crossbred dairy cows is considered, the average agricultural household consumption expenditure for adopters is about 220 US $ per month. Attributing such a large difference in income between adopters and non-adopters to the use of crossbred dairy cows only could be misleading if adoption of crossbred cows is confounded with unobservable variables. In the next section, we present results of the propensity score matching and the sample treatment effect estimator, which accounts for the effects of unobservable variables.

Table 1. Mean differences in key farm resources and welfare indicators between adopters and non-adopters of improved dairy technologies in Ethiopia

Variables	Crossbred dairy cows			Improved forages		
	Adopters (n=30)	Non-adopters (n=639)	Diff.	Adopters (n=49)	Non-adopters (n=609)	Diff.
Household dietary diversity score (HDDS)	5.63	4.54	1.09***	5.33	4.51	0.82***
Household income(US$)	286	66	220***	141	71	69***
Age of household head (y)	51.90	46.74	5.16	47.47	46.93	0.54
Gender of household head (1=Male)	0.87	0.84	0.03	0.98	0.83	0.15***
Marital status of household head (1=married)	0.87	0.84	0.03	0.92	0.83	0.09
Education level of household head (y)	3.97	4.07	-0.11	3.73	4.10	-0.36
Number of family members of working age	5.23	3.63	1.60***	4.16	3.67	0.49
Dependency ratio[1]	0.53	0.85	-0.32**	0.82	0.83	-0.01
Total land holding (ha)	1.22	1.74	-0.53	1.21	1.76	-0.55*
Total livestock holding (TLU[2])	5.76	5.20	0.54	5.26	5.24	0.02
Oxen holding (TLU)	2.27	1.85	0.42	1.92	1.86	0.06
Ownership of mobile telephone (1=yes)	0.70	0.33	0.37***	0.55	0.34	0.22***
Distance to nearest market centre (km)	8.48	9.27	-0.79	11.34	4.26	7.08***
Distance to Farmer Training Centre (km)[3]	3.52	4.84	-1.33	11.7	9.03	2.67**

Notes: *** p<0.01, ** p<0.05, * p<0.1

4.4.2. Propensity Score Matching

In the logit model used for estimation of propensity scores, the likelihood ratio tests [(χ^2 (6) = 23.22, P < 0.00] for crossbred dairy cows and [χ^2 (6) = 26.30, P < 0.00] for improved forages indicates that the included covariates had adequately estimated the propensity scores. After matching, pseudo-R^2 was 0.13 for crossbred cows and 0.06 for improved forages. The fairly low pseudo- R^2 is plausible, after matching there should be no systematic differences in the distribution of covariates between both groups.

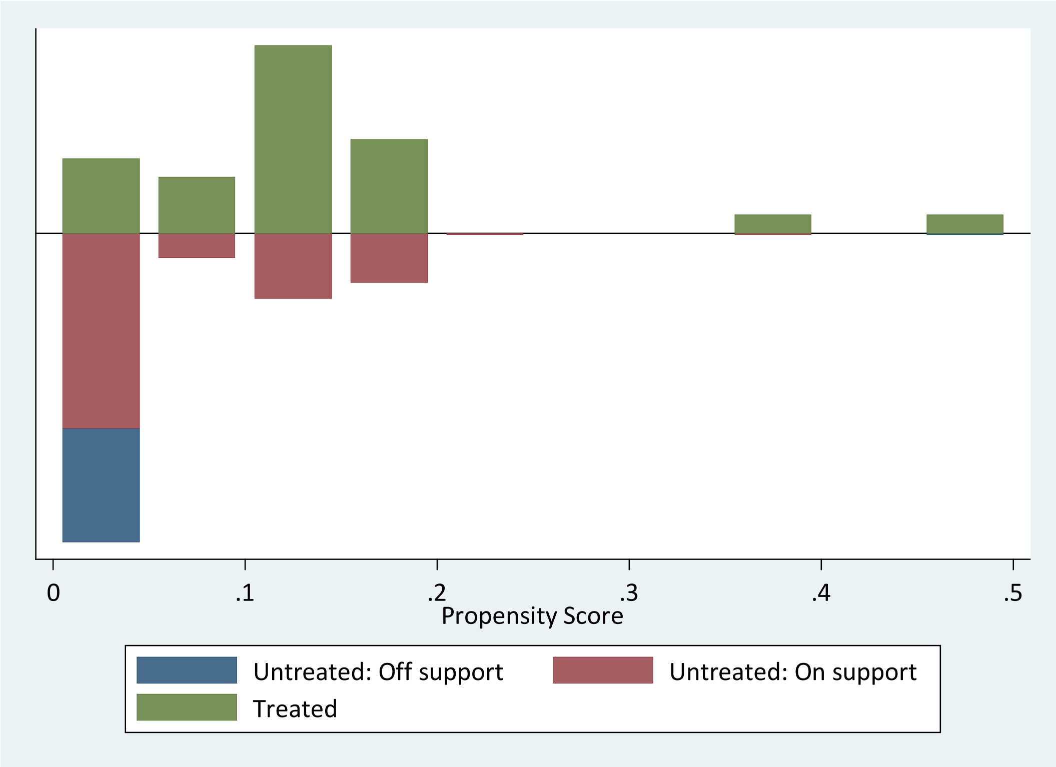

Figure 1. Propensity score distribution and common support for propensity score estimation of crossbred dairy cows. Y-axis shows the frequencies of propensity scores.

The balancing test results show that the selected subsample of the original dataset was balanced in the covariates for both crossbred dairy cows and improved forages (see Appendix Tables 1 and 2). The unconfoundedness (or selection on observables) assumption postulates that systematic differences in outcomes between treated and comparison individuals with the same values for covariates are attributable to treatment. Visual inspection of the frequencies of the estimated propensity scores of adopters and non-adopters for crossbred dairy cows showed some matching in propensity scores (Figure 1). There were sufficient numbers of non-adopters that match with adopters at the lower end of the propensity scores. At the higher ends of the propensity scores, the number of non-adopters matching with adopters were scarce. Therefore, the common support condition was slightly satisfied.

The histogram of the estimated propensity scores for adopters and non-adopters of improved forages shows almost similar distributions of propensity scores for adopters and non-adopters (Figure 2). Only for the very high propensity scores in the adopters group, no

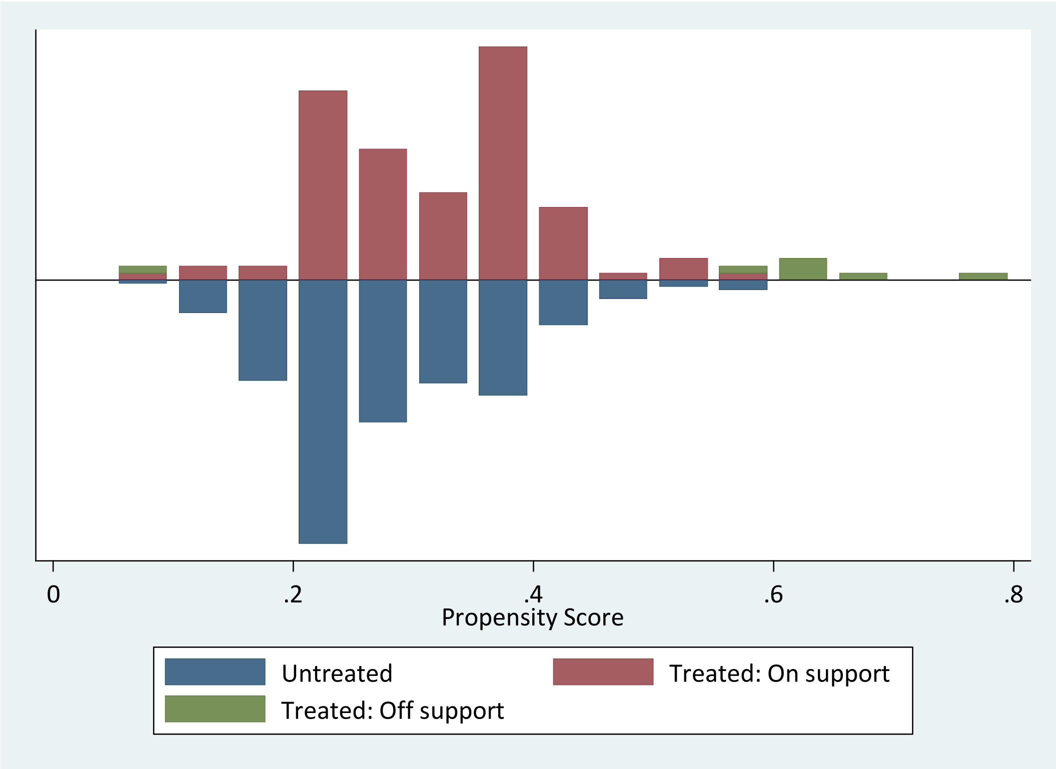

Figure 2. Propensity score distribution and common support for propensity score estimation of improved forages. Y-axis shows the frequencies of propensity scores.

matching non-adopters could be found. Therefore, the unconfoundedness assumption was satisfied for the adoption of improved forages.

Rosenbaum sensitivity test: For adoption of crossbred dairy cows, the Rosenbaum sensitivity test showed that the log odds of differential assignment due to unobservable factors was significant for household income impact of dairy crossbred cow adoption at Γ = 1 (Table 2). Moreover, the Rosenbaum sensitivity test also showed that log odds of differential assignment due to unobservable factors are significant for both HDDS and household income for both dairy technologies at Γ=2 and Γ= 3 (see Table 2). This indicates that unobservable variables potentially confound treatment effect. This calls for the use of an alternative strategy to estimate adoption impacts. In the following section we first present PSM results followed by sample treatment effect estimator results.

Impact of dairy technology adoption on household nutrition status and income: The PSM results show that adoption of crossbred dairy cows and improved forages increased HDDS and income (Table 3). The ATT values imply that adopters of crossbred dairy cows had 0.69

Table 2. Rosenbaum sensitivity test of effect of unobservable variables on dairy technology adoption

Adoption of:	Household welfare indicator	Γ = 1	Γ = 2	Γ = 3
Crossbred dairy cows	HDDS	1.00	L: 2.00**	L: 2.50***
			U: -0.01	U: -0.50***
	Income	103.06**	L: 310.96	L: 395.00***
			U: 24.25***	U: -2.82
Improved forages	HDDS	0.50	L: 1.00	L: 1.50
			U: -0.50***	U: -1.00
	Income	-5.90	L: 28.56	L: 51.18
			U: -34.41***	U:-54.01***

Note: *** p<0.01, ** p<0.05, * p<0.1
L = Lower bound; U = Upper bound on the *P* levels for testing no effect.

Table 3. Crossbred dairy cows and improved forages adoption effects on household dietary diversity score and income (US$ per household per year)

Adoption of:	Household welfare indicator	Kernel matching		
		ATE	ATT	ATU
Crossbred dairy cow	HDDS	0.06	0.69***	0.01*
	Income	152.87	217.75***	147.42**
Improved forages	HDDS	0.66	0.66***	0.65**
	Income	40.34	63.33***	37.22**

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

higher HDDS and 217.75 US$ higher household income per annum than their non-adopter counterparts. Similarly, adoption of improved forages on average increased HDDS by 0.66 and household income by 63.33 US$ per household per year. The ATU estimates of the counterfactual outcomes show that all welfare indicators would improve if non-adopters would adopt crossbred cows and improved forages.

Table 4 shows results of impact analysis by the sample treatment effect estimator. Again adoption of crossbred dairy cows and improved forages increased household HDDS and income and the effect of adoption of crossbred dairy cows was higher than of adoption of

Table 4. Sample treatment effect estimator results of crossbred dairy cows and improved forages adoption effect on household nutrition and income (US$ per household per year)

Intervention	Household welfare indicator	Sample treatment effect estimator		
		SATE	SATT	SATU
Crossbred dairy cow	HDDS	1.31***	1.08***	1.33***
	Income	226.56***	196.08***	228.55***
Improved forages	HDDS	0.71***	0.53*	0.74**
	Income	46.36*	67.84***	48.20*

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

improved forages. The differences in values between Tables 3 and 4 can be attributed to effects of considering unobservable variables in the analysis. The largest difference between PMS and the sample treatment effect estimator was found for ATU, indicating that unobservable variables have substantial influence on the impacts of dairy technology adaption among non-adopters.

4.5. Discussion

This study examined the difference in household nutrition status and income between adopters and non-adopters of dairy technologies using the propensity score matching method and the sample treatment effect estimator. The results consistently show that adopting improved dairy technologies increases household nutrition status and income. The results further demonstrate that PSM is an effective estimator of treatment effects, as far as the overlap in the covariate distribution is good, while the sample treatment effect estimator may be more effective when overlap is poor. The positive impact of using dairy technologies on household nutrition and income is consistent with the perceived role of new agricultural technologies in reducing food insecurity and poverty (Jera and Ajayi, 2008; Kristjanson et al., 2007). The impact estimates using the sample treatment effect estimator were comparable and consistent with the impact estimates by PSM. The higher counterfactual adoption impact of crossbred dairy cows on non-adopters suggests that farmers with comparable resource ownership could have made substantial gains if they had adopted. As compared to PSM, the magnitude of counterfactual impacts with respect to household dietary diversity score and income estimated by the sample treatment effect estimator are relatively higher. The difference between the magnitudes of counterfactual impacts between the two methods could be due to bias resulting from unobservable factors that led to under-estimation and over-estimation of treatment effects by PSM. The heterogeneity among smallholders could be the reason why many farmers appear to avoid the technologies promoted for their supposed benefit the Ethiopian highlands. The result further confirms the rationale behind resource constrained farmers' persistent rejection of crossbred dairy cows despite many years of research and development efforts.

Given the low numbers of adopters relative to the large number of non-adopters, however, the results may not be generalizable to the whole population. The impact estimation based on limited numbers of sample adopters may not consistently estimate adoption impact for the population (Busso et al., 2014). As indicated by the Rosenbaum sensitivity test, the PSM impact estimates are sensitive to bias due to unobservable factors. Often, differences in biophysical, institutional, economic and cultural environments account for the unobservable heterogeneity among agricultural household (Kabunga et al., 2012; Kabunga et al., 2014). These factors could interfere with determination of the impact of dairy technology adoption on welfare outcomes and the differences between estimates from PSM and the sample treatment effect estimator imply that unobservable variables indeed influence impact. The results of the sample treatment effect estimator are also valid only for a subsample of agricultural households more balanced in the covariates. Given the differences in biophysical, institutional, economic and cultural environments facing different groups of farmers, agricultural households' decisions not to adopt technically beneficial technologies may actually be an optimal decision for majority of resource poor farmers.

4.6. Conclusions

The aim of this study was to test whether adopting dairy technologies has an impact on agricultural household nutrition and income for adopters and whether adopting dairy technologies would have impact on nutrition and income for non-adopters if they decided to adopt the interventions. We examined the difference in nutritional status and income between adopters and non-adopters of dairy technologies using propensity score matching and the sample treatment effect estimator. The results show that adopting improved dairy technologies generally increases household nutrition and income. Particularly, adopting crossbred dairy cows has a substantial effect on household income for adopters. The impact of adopting improved forages on household nutrition and income was smaller. The counterfactual impact estimates also show that non-adopters could derive considerable benefit with respect to income from adopting crossbred cows and improved forages, should they decide to adopt. The results reported in this paper provide indications that adoption of improved dairy technologies improves rural households' welfare. While our results could provide good guidance on the average effect of technology adoption on household welfare, nevertheless, the result may have low predictive power across population subgroups. Therefore, further investigations with particular emphasis to political, social and economic processes that underlie differential welfare outcomes, are needed to test whether the results of this paper could be generalizable for the majority of farmers in developing countries.

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Appendix Table 1

```
. pscore xbreedcow sex age activelabforc  ICT distancefarmertrainingcentre2, psc(
> ckid (myblock) comsup numblo(5) level (0.05)logit


****************************************************
Algorithm to estimate the propensity score
****************************************************


The treatment is xbreedcow

adoption of |
  crossbred |
cows yes/no |      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |        368       93.88       93.88
          1 |         24        6.12      100.00
------------+-----------------------------------
      Total |        392      100.00


Estimation of the propensity score

Iteration 0:   log likelihood = -90.286828
Iteration 1:   log likelihood = -81.695263
Iteration 2:   log likelihood = -78.788211
Iteration 3:   log likelihood = -78.684019
Iteration 4:   log likelihood = -78.676448
Iteration 5:   log likelihood = -78.676433

Logistic regression                               Number of obs   =        392
                                                  LR chi2(5)      =      23.22
                                                  Prob > chi2     =     0.0003
Log likelihood = -78.676433                       Pseudo R2       =     0.1286

------------------------------------------------------------------------------
   xbreedcow |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         sex |  -.2480923   .7944989    -0.31   0.755    -1.805282    1.309097
         age |   .0141747   .0155128     0.91   0.361    -.0162298    .0445791
activela~orc |    .155615   .0940745     1.65   0.098    -.0287676    .3399976
         ICT |    1.73861   .5268377     3.30   0.001     .7060274    2.771193
distancefa~2 |  -.2867564   .5583482    -0.51   0.608    -1.381099    .8075859
       _cons |  -4.791139   1.161147    -4.13   0.000    -7.066945   -2.515332
------------------------------------------------------------------------------


Note: the common support option has been selected
The region of common support is [.01333763, .33567366]


Description of the estimated propensity score
in region of common support

                 Estimated propensity score
-------------------------------------------------------------
      Percentiles      Smallest
 1%     .0135298       .0133376
 5%     .0141005       .0135083
10%     .0157669       .0135083       Obs                 337
25%     .0204916       .0135298       Sum of Wgt.         337

50%     .0346765                      Mean           .0670876
                        Largest       Std. Dev.      .0609573
75%      .103713       .2522522
90%      .148956       .2720067       Variance       .0037158
95%     .1791402       .3171842       Skewness       1.387172
99%     .2522522       .3356737       Kurtosis       4.797165


******************************************************
Step 1: Identification of the optimal number of blocks
Use option detail if you want more detailed output
******************************************************


The final number of blocks is 5

This number of blocks ensures that the mean propensity score
is not different for treated and controls in each blocks



**********************************************************
Step 2: Test of balancing property of the propensity score
Use option detail if you want more detailed output
**********************************************************


The balancing property is satisfied


This table shows the inferior bound, the number of treated
and the number of controls for each block

  Inferior |  adoption of crossbred
  of block |      cows yes/no
 of pscore |         0          1 |     Total
-----------+----------------------+----------
  .0133376 |       238         10 |       248
        .1 |        52          4 |        56
       .15 |        12          7 |        19
        .2 |        11          1 |        12
        .3 |         0          2 |         2
-----------+----------------------+----------
     Total |       313         24 |       337

Note: the common support option has been selected


*******************************************
End of the algorithm to estimate the pscore
*******************************************
```

Appendix Table 2

```
. pscore improvedforages sex age hheducation activelabforc totaltlu distancefarmertraining
> centre2, pscore(p) blockid (myblock) comsup numblo(5) level (0.05)logit


****************************************************
Algorithm to estimate the propensity score
****************************************************


The treatment is improvedforages

improvedfor |
       ages |      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |        277       70.66       70.66
          1 |        115       29.34      100.00
------------+-----------------------------------
      Total |        392      100.00


Estimation of the propensity score

Iteration 0:   log likelihood =  -237.2146
Iteration 1:   log likelihood = -224.48407
Iteration 2:   log likelihood = -224.14715
Iteration 3:   log likelihood = -224.07183
Iteration 4:   log likelihood = -224.06318
Iteration 5:   log likelihood = -224.06317

Logistic regression                               Number of obs   =        392
                                                  LR chi2(6)      =      26.30
                                                  Prob > chi2     =     0.0002
Log likelihood = -224.06317                       Pseudo R2       =     0.0554

------------------------------------------------------------------------------
improvedfo~s |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         sex |   .2675533   .4863743     0.55   0.582    -.6857227    1.220829
         age |  -.0038577   .0087128    -0.44   0.658    -.0209344    .0132191
 hheducation |  -.1961162    .064002    -3.06   0.002    -.3215579   -.0706745
activela~orc |     .12959   .0578675     2.24   0.025     .0161718    .2430083
    totaltlu |  -.0596232    .028407    -2.10   0.036    -.1152999   -.0039466
distancefa~2 |   .2635477   .2631666     1.00   0.317    -.2522493    .7793447
       _cons |  -.5134342   .6599226    -0.78   0.437    -1.806859    .7799904
------------------------------------------------------------------------------


Note: the common support option has been selected
The region of common support is [.06029723, .99975961]


Description of the estimated propensity score
in region of common support

                 Estimated propensity score
-------------------------------------------------------------
      Percentiles      Smallest
 1%     .1019774       .0602972
 5%     .1382417       .0763304
10%     .1655056       .0840641       Obs                 391
25%     .2090765       .1019774       Sum of Wgt.         391

50%     .2778805                      Mean           .2939733
                        Largest       Std. Dev.      .1171487
75%      .361442       .6232302
90%     .4559514       .6388379       Variance       .0137238
95%     .4873695       .6819738       Skewness       1.083367
99%     .6232302       .9997596       Kurtosis        5.93707


******************************************************
Step 1: Identification of the optimal number of blocks
Use option detail if you want more detailed output
******************************************************


The final number of blocks is 6

This number of blocks ensures that the mean propensity score
is not different for treated and controls in each blocks



**********************************************************
Step 2: Test of balancing property of the propensity score
Use option detail if you want more detailed output
**********************************************************


The balancing property is satisfied


This table shows the inferior bound, the number of treated
and the number of controls for each block

  Inferior |
  of block |    improvedforages
 of pscore |         0          1 |     Total
-----------+----------------------+----------
  .0602972 |        66         15 |        81
        .2 |       111         31 |       142
        .3 |        66         33 |        99
        .4 |        32         32 |        64
        .6 |         1          3 |         4
        .8 |         0          1 |         1
-----------+----------------------+----------
     Total |       276        115 |       391

Note: the common support option has been selected


*******************************************
End of the algorithm to estimate the pscore
*******************************************
```

Appendix Table 3: Sensitivity analysis of crossbred dairy cows

```
. rbounds deltahdd, gamma(1 (1) 3)alpha(.95)

Rosenbaum bounds for deltahdd (N = 24 matched pairs)

Gamma           sig+      sig-    t-hat+    t-hat-       CI+       CI-
----------------------------------------------------------------------
    1        .062922   .062922         1         1  -2.6e-07       2.5
    2        .433102    .00104  -2.6e-07         2        -1       3.5
    3        .728611   .000017       -.5       2.5        -2       4.5

* gamma  - log odds of differential assignment due to unobserved factors
  sig+   - upper bound significance level
  sig-   - lower bound significance level
  t-hat+ - upper bound Hodges-Lehmann point estimate
  t-hat- - lower bound Hodges-Lehmann point estimate
  CI+    - upper bound confidence interval (a=  .95)
  CI-    - lower bound confidence interval (a=  .95)

. rbounds deltahdd, gamma(1 (1) 3)sigonly

Rosenbaum bounds for deltahdd (N = 24 matched pairs)

Gamma           sig+      sig-    t-hat+    t-hat-       CI+       CI-
----------------------------------------------------------------------
    1        .062922   .062922         0         0         0         0
    2        .433102    .00104         0         0         0         0
    3        .728611   .000017         0         0         0         0

* gamma  - log odds of differential assignment due to unobserved factors
  sig+   - upper bound significance level
  sig-   - lower bound significance level
  t-hat+ - upper bound Hodges-Lehmann point estimate
  t-hat- - lower bound Hodges-Lehmann point estimate
  CI+    - upper bound confidence interval (a=  .95)
  CI-    - lower bound confidence interval (a=  .95)

.
end of do-file

. rbounds deltaexp, gamma(1 (1) 3)alpha(.95)

Rosenbaum bounds for deltaexp (N = 24 matched pairs)

Gamma           sig+      sig-    t-hat+    t-hat-       CI+       CI-
----------------------------------------------------------------------
    1        .019836   .019836   103.058   103.058   6.31283   378.406
    2        .252482   .000109   26.2645   326.878  -63.1024   585.821
    3        .539421   6.2e-07  -2.81869   394.195  -101.629   733.055

* gamma  - log odds of differential assignment due to unobserved factors
  sig+   - upper bound significance level
  sig-   - lower bound significance level
  t-hat+ - upper bound Hodges-Lehmann point estimate
  t-hat- - lower bound Hodges-Lehmann point estimate
  CI+    - upper bound confidence interval (a=  .95)
  CI-    - lower bound confidence interval (a=  .95)

. rbounds deltaexp, gamma(1 (1) 3)sigonly

Rosenbaum bounds for deltaexp (N = 24 matched pairs)

Gamma           sig+      sig-    t-hat+    t-hat-       CI+       CI-
----------------------------------------------------------------------
    1        .019836   .019836         0         0         0         0
    2        .252482   .000109         0         0         0         0
    3        .539421   6.2e-07         0         0         0         0

* gamma  - log odds of differential assignment due to unobserved factors
  sig+   - upper bound significance level
  sig-   - lower bound significance level
  t-hat+ - upper bound Hodges-Lehmann point estimate
  t-hat- - lower bound Hodges-Lehmann point estimate
  CI+    - upper bound confidence interval (a=  .95)
  CI-    - lower bound confidence interval (a=  .95)

.
end of do-file
```

Appendix Table 4: Sensitivity analysis of improved forages

```
. rbounds deltahdd, gamma(1 (1) 3)alpha(.95)

Rosenbaum bounds for deltahdd (N = 108 matched pairs)

Gamma           sig+      sig-    t-hat+    t-hat-       CI+       CI-
----------------------------------------------------------------------
    1        .104162   .104162        .5        .5  -3.3e-07         1
    2        .965056   3.7e-06       -.5         1        -1       1.5
    3        .999886   2.2e-11        -1       1.5      -1.5         2

* gamma  - log odds of differential assignment due to unobserved factors
  sig+   - upper bound significance level
  sig-   - lower bound significance level
  t-hat+ - upper bound Hodges-Lehmann point estimate
  t-hat- - lower bound Hodges-Lehmann point estimate
  CI+    - upper bound confidence interval (a=  .95)
  CI-    - lower bound confidence interval (a=  .95)

. rbounds deltahdd, gamma(1 (1) 3)sigonly

Rosenbaum bounds for deltahdd (N = 108 matched pairs)

Gamma           sig+      sig-    t-hat+    t-hat-       CI+       CI-
----------------------------------------------------------------------
    1        .104162   .104162         0         0         0         0
    2        .965056   3.7e-06         0         0         0         0
    3        .999886   2.2e-11         0         0         0         0

* gamma  - log odds of differential assignment due to unobserved factors
  sig+   - upper bound significance level
  sig-   - lower bound significance level
  t-hat+ - upper bound Hodges-Lehmann point estimate
  t-hat- - lower bound Hodges-Lehmann point estimate
  CI+    - upper bound confidence interval (a=  .95)
  CI-    - lower bound confidence interval (a=  .95)

.
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. rbounds deltaexpenforage, gamma(1 (1) 3) alpha(.95)

Rosenbaum bounds for deltaexpenforage  (N = 108 matched pairs)

Gamma           sig+      sig-    t-hat+    t-hat-       CI+       CI-
----------------------------------------------------------------------
    1        .293727   .293727  -5.89718  -5.89718  -23.4588    15.847
    2        .000083   .995524  -34.4137   28.5636    -58.66   57.8807
    3        2.7e-09   .999998  -54.0131   51.1781  -92.8273   90.2761

* gamma  - log odds of differential assignment due to unobserved factors
  sig+   - upper bound significance level
  sig-   - lower bound significance level
  t-hat+ - upper bound Hodges-Lehmann point estimate
  t-hat- - lower bound Hodges-Lehmann point estimate
  CI+    - upper bound confidence interval (a=  .95)
  CI-    - lower bound confidence interval (a=  .95)

. rbounds deltaexpenforage, gamma(1 (1) 3)sigonly

Rosenbaum bounds for deltaexpenforage (N = 108 matched pairs)

Gamma           sig+      sig-    t-hat+    t-hat-       CI+       CI-
----------------------------------------------------------------------
    1        .293727   .293727         0         0         0         0
    2        .000083   .995524         0         0         0         0
    3        2.7e-09   .999998         0         0         0         0

* gamma  - log odds of differential assignment due to unobserved factors
  sig+   - upper bound significance level
  sig-   - lower bound significance level
  t-hat+ - upper bound Hodges-Lehmann point estimate
  t-hat- - lower bound Hodges-Lehmann point estimate
  CI+    - upper bound confidence interval (a=  .95)
  CI-    - lower bound confidence interval (a=  .95)

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Chapter 5

Understanding socio-economic and policy constraints to dairy development in Ethiopia through innovation systems function analysis

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Abstract

This study investigates how the Ethiopian dairy innovation system has functioned to support the development of the Ethiopian dairy sector and what have been the major technical, economic and institutional constraints in the process. We used a coupled functional-structural analysis of innovation systems to analyse the influence of socio-economic and policy constraints on the development of the Ethiopian dairy sector. Results show that problems with structural elements such as the absence of key actors, limited capacity of existing actors, insecure property rights, cumbersome bureaucratic processes, poor interaction among actors and inadequate infrastructure have all limited dairy innovation. Out of the seven innovation functions studied, our findings show that entrepreneurship, knowledge diffusion, market development and legitimacy creation have been particularly weak. We conclude that problems with the structural elements coupled with weak innovation system functions have been major hindrances to the uptake of technologies and dairy sector development in Ethiopia. The narrow policy focus on biophysical technology generation and dissemination, without considering the underlying problems related to institutional conditions and socio-economic processes, has also contributed to low technology adoption and broader development in the dairy sector. We suggest that combinations of institutional and technological interventions are needed to overcome the various system blockages that have hindered dairy sector development.

5.1. Introduction

The demand for milk products is increasing in Ethiopia in response to population growth, income growth and urbanisation (Francesconi et al., 2010; Jaleta et al., 2013). Liquid milk production in Ethiopia, however, has not kept pace with the growing demand as a result of a lagging development of the dairy sector. Researchers, development practitioners and policy makers are faced with the challenge of meeting the increasing demand for milk and other animal-source foods on a shrinking land and water resource base and under increasing challenges of climate change (Thornton, 2010). Meanwhile, currently available technologies and organisational innovations provide potential opportunities for smallholder dairy development. Since 1960s, various technological interventions including improved breeds of dairy cattle, improved forages and animal health interventions have been promoted to enhance the productivity of dairy cattle in Ethiopia (Ahmed et al., 2004). On the organisational side, dairy cooperatives have been promoted to enhance farmers' access to markets (Bernard and Spielman, 2009). Despite the potential of these technological and organisational interventions to increase productivity of the dairy cattle, adoption levels of the interventions have been low (Duncan et al., 2013). Recent studies in Ethiopia indicate that the total production of cow milk is about 4.1 billion litres, which translates to an average daily milk production per cow of 1.9 litres per day (Tegegne et al., 2013). This raises the question as to why farmers in Ethiopia are unable to take advantage of new technologies and economic opportunities in the dairy sector. What obstacles prevent simple productive technologies and organisational interventions from spreading to Ethiopian smallholders, given the wealth of global knowledge on technological aspects of dairy production?

Given this apparent blockage to dairy development it is not surprising that there are many empirical studies that have explored the basis for the lack of widespread adoption of agricultural technologies and related organisational interventions in the dairy sector (Kristjanson et al., 2005; Ran et al., 2013; Spielman et al., 2011). Most adoption studies have concluded that factors associated with market failures, such as inefficiencies in input and output markets, imperfect land, labour, credit and insurance markets and information inefficiencies explain low technology adoption. Although these adoption studies have provided insights into important technology adoption constraints, relevant factors at the level of value chains and macroeconomic policy context are not understood in ways that help formulation of interventions to address the constraints (Barrett et al., 2010; Hounkonnou et al., 2012; Klerkx et al., 2010). Empirical studies that explore technology adoption constraints have thus not been able to unravel the constraints rooted at the level of communities, groups, markets and the macro-economy (Birner and Resnick, 2010; Bleda and del Río, 2013; Doss, 2006). Furthermore, existing studies have tended to focus on externally generated technologies (i.e. in research institutes instead of on farmers' fields) and have overlooked the possibilities of locally generated 'grassroots innovations' (Waters-Bayer et al., 2009). Specifically in the case of animal production systems, the use of systems approaches can help to analyse the barriers to the uptake of improved technologies (Jiggins, 2001). Such systems research on dairy production in developing countries is in short supply, and existing studies in Ethiopia have been restricted to social network analyses (Asres et al., 2012; Spielman et al., 2011).

The role of the socio-economic and political context in the generation and wider application of agricultural technology has been acknowledged in the agricultural innovation systems (AIS) approach (Amankwah et al., 2012; Klerkx et al., 2010; van Mierlo et al., 2010). The AIS approach recognises the role of actors, institutions, interactions between actors, infrastructure and the historical dynamics of innovation processes (Adjei-Nsiah et al., 2008). This study follows an innovation systems approach to help in understanding the macro-level socio-economic and political issues that hinder smallholder dairy development in Ethiopia as a case study. The main question of this paper is how different innovation system elements have contributed to the functioning of the smallholder dairy sector in Ethiopia, and how this has influenced its development. The paper analyses the historical evolution of the macro-level institutional environment and socio-economic processes using the elements of the functional-structural analysis framework (Wieczorek and Hekkert, 2012), and suggests interventions that could deal with the identified constraints to technology adoption and dairy development in Ethiopia. Identifying institutional constraints also guides research and policy to come up with effective instruments that could stimulate institutional and technical change and spur agricultural productivity in developing countries in general.

5.2. Conceptual framework

Since the emergence of innovation systems approach, a number of conceptual frameworks have been developed to study the constraints to innovation and technological change. Structural analysis and systemic failures frameworks have been used to evaluate composition of innovation systems (Bergek et al., 2008; Edquist, 2005; Lundvall, 1988; Malerba, 2002). Innovation systems functions approach has been used to analyse sustainability oriented technological innovation (e.g., solar cell technology, wind energy) (Hekkert and Negro, 2009; Hekkert et al., 2007). Analysis of structural elements has been previously applied to study agricultural innovation systems in both developed and developing countries (Amankwah et al., 2012; Totin et al., 2012; Turner et al., 2013). Functional analysis has been suggested as a promising approach to analyse agricultural innovation systems in developing countries (Rajalahti et al., 2008). Even though the different frameworks were developed separately from each other, they were all intended to study the constraints to innovation and technological change. Wieczorek and Hekkert (2012) proposed a functional-structural analysis framework which brings together the different conceptual frameworks into a comprehensive functional–structural analysis framework. The coupled functional–structural analysis framework provides a general representation of relationships among structural elements, systemic problems, innovation system functions and systemic instruments. In this study we adapted the coupled functional–structural analysis framework proposed by Wieczorek and Hekkert (2012) to unravel the underlying constraints to innovation and technological change in the dairy sector in Ethiopia. The key components of the functional–structural analysis framework and their relationships are described in the following sub-sections.

5.2.1. Functional analysis

Functions of an innovation system are the types of activities (with associated event types) necessary to build-up the technological innovation system (Bergek et al., 2008; Hekkert et al., 2007; Suurs et al., 2010). In this paper, events refer to policies, programs and projects relevant to dairy development implemented in Ethiopia since the 1950s to the present day, and dairy development is hence seen as a technological innovation system. Within the systemic innovation policy framework, the functions are analysed through the perspective of the structural elements. Seven key functions are outlined in the literature: entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search, market formation, resource mobilisation and creation of legitimacy. A brief description of the system functions and associated event types is given in Table 1.

Table 1. Description of the seven functions of innovation systems

System function	Description
F1. Entrepreneurial Activities	At the core of any innovation system are the entrepreneurs (i.e. farmers, processors, etc.). These entrepreneurs exploit business opportunities and perform innovative commercial and/or practice oriented experiments
F2. Knowledge Development	Technological research and development are a source of variation in the system and are therefore prerequisites for innovation processes to occur. Non-technological knowledge is also of key importance
F3. Knowledge Diffusion	The typical organisational structure of a well-functioning innovation system is the knowledge network, primarily facilitating information exchange
F4. Guidance of the Search	Represents policies and strategies which set a clear vision, targets and necessary for the dairy sector and serves to focus resources
F5. Market Formation	New technologies often cannot outperform established ones. To stimulate innovation it is necessary to facilitate the creation of (niche) markets, where new technologies have a possibility to grow
F6. Resource Mobilisation	Financial, material and human resources are necessary inputs for innovation system development
F7. Creation of legitimacy	Innovation often leads to resistance from established actors. In order for innovations to develop and transformative change to occur, actors need to raise a political lobby that counteracts this inertia and supports the new technology

Note: Adapted from Suurs et al. (2010)

5.2.2. Structural analysis

The performance of the seven functions of the innovation system is influenced by so-called structural elements. All aspects of the economic structure and the institutional set up affecting the learning, searching and exploration are defined as structural elements of innovation systems (Wieczorek and Hekkert, 2012). The four structural elements identified in the literature are: (i) actors, (ii) institutions (iii) interactions and (iv) infrastructure (See Table 2).

Table 2. Structural elements of technological innovation system

Structural elements	Sub-categories
Actors	• Civil society • Companies: input suppliers, market agents, large firms • Knowledge institutes: university research labs, technology institutes, research centres • Government at all levels • Non-governmental organisations (NGOs) • Other parties: legal organisations, financial organisations/banks, intermediaries, knowledge brokers, consultants
Institutions	• Hard: rules, laws, regulations, instructions • Soft: customs, common habits, routines, established practices, traditions, ways of conduct, norms, expectations
Interactions	• At the level of networks • At the level of individual contacts
Infrastructure	• Physical: machines and equipment (e.g., bulking and cooling, storage, processing), roads, buildings, networks, bridges • Knowledge: knowledge about inputs (e.g., improved breeds of dairy cattle and planting of improved forages), dairy management techniques (e.g., for preservation, transporting, marketing), business skills • Financial: Financial programs (e.g., micro-loans), subsidies, grants, etc.

Note: Adapted from Wieczorek and Hekkert (2012)

When the structural elements do not perform well, the outcomes are so-called ‘system failures’ or ‘systemic problems’. Lamprinopoulou et al (2014) has summarised system failures based on extensive review of the literature on the topic (Klein Woolthuis et al., 2005; Klerkx et al., 2012; Weber and Rohracher, 2012; Wieczorek and Hekkert, 2012) as follows:

- *Capability failure* refers to the absence of the necessary capabilities to adapt to new and changing circumstances and (technological) opportunities.
- *Demand articulation failure* refers to problems associated with joint learning processes and influence of stakeholders on the formulation and execution of development, innovation and research agenda.
- *Institutional failure* refers to problems associated with either laws, regulations or other formalised rules (the so-called ‘hard institutions’), or informal rules, common habits, routines and shared norms/values used by humans in repetitive situations (the co-called ‘soft institutions’).
- *Interaction failures* refer to actors locked into their relationships, which causes myopia, blocks new ideas from outside and prohibits other potentially fruitful collaborations. They may occur at either a network level or at the level of bilateral contacts between

individuals. These are the so-called 'strong network failures'. The so-called 'weak network failures' refer to situations where actors are not well connected in fruitful cycles of learning and innovation.

- *Market structure failures* refer to the problems associated with the positions of, and relations between market parties. Such failures include monopolies or the lack of transparency in the ever enlarging food chains.
- *Infrastructural failures* concern inadequacies of the physical infrastructures such as railroads telecoms, machines, buildings. They also concern investments in knowledge infrastructure and financial infrastructure (e.g. subsidies, grants, incentives from banks, etc.).
- *Directionality failure* refers to the lack of shared vision and inability of collective coordination of fragmented change agents. It implies that development and change is closely linked to direction and the setting of collective priorities for the system.
- *Policy coordination failure* refers to coordination and coherence problems at different policy levels in innovation systems.
- *Reflexivity failure* concerns with insufficient ability of the system to engage actors in a self-governance process, to monitor progress against the transformational goals, and to anticipate and develop adaptation strategies.

The coupled functional-structural analysis links systemic problems with the various innovation system functions to identify the factors that block specific functions and hinder development of the innovation system and to identify potential instruments for improvement. However, on a more positive note, the systemic failure categories can also be used to indicate 'system merits'(Lamprinopoulou et al., 2014).

5.3. Research methods

5.3.1. Data collection

The sources of information for this study included document review, focus group discussions and key informant interviews, as is typical for this type of innovation system analysis (Hekkert et al., 2007; Negro et al., 2012). While document reviews were done at national and regional level, key informant interviews and focus group discussions were held at Fogera, Jeldu and Diga districts in the Blue Nile Basin (locally known as Abbay basin) in Ethiopia.

a) *Document review:* we reviewed the literature from the 1950s to 2013 to construct a history of the dairy innovation system in Ethiopia. Given the interest and scope of this study, only initiatives with national significance to the dairy sector development were considered. The information was obtained particularly from government policy documents, program outcome reports, project and program evaluation reports, books, book chapters, working papers, peer reviewed journal articles and information from websites of relevant organisations [e.g., International Livestock Research Institute (ILRI), The Food and Agriculture Organisation of the United Nations (FAO), Intergovernmental Authority on Development (IGAD) Livestock Policy Initiative (IGAD-LPI)]. The occurrence of the various events that we documented was cross-referenced using published materials wherever possible.

b) *Key informant interviews*: To complement the information obtained from literature, we conducted in-depth interviews with a minimum of two key informants from each of the following actor types in the three study districts: experienced livestock researchers, heads of the agricultural extension offices, development agents, traders and community elders. All key informants were locally recognised to be knowledgeable in the field. The interviews mostly took place in offices and on farmers' fields.

c) *Focus group discussions:* Focus group discussions were conducted from October 2011 to February 2012. Twelve separate focus group discussions (each focus group comprising 3-6 participants) were held with office heads and experienced researchers from Amhara and Oromia Regional Agricultural Research Institutes, Holeta Agricultural Research Centre, Bako Agricultural Research Centre, Andassa Agricultural Research Centre, Bahir Dar University, Wollega University, Amhara and Oromia Regional Livestock Development and Health Agency, District offices of Agriculture, Regional and District Offices of Finance and Economic Development, and District offices of Micro and Small Enterprises Development. Six separate focus group discussions (each group comprising 2-5 participants) were held with dairy cooperatives, private dairy farmers owning crossbred dairy cows, private veterinary service providers, drug suppliers, traders, and community elders using a standardized checklist for discussion. The participants were asked for their opinion about the key issues associated with major livestock development programs, structural elements, systemic problems and functions of the dairy innovation system in Ethiopia.

5.3.2. Analytical approach

The conceptual framework presented in the previous section requires tools which help analyse the events that have shaped each element of the framework over time. We used event history analysis to assess the events that shaped each element of the structural-functional analysis framework over time (Hekkert and Negro, 2009; Van de Ven et al., 1999). The event history assesses the structural elements affecting fulfilment of the innovation functions and draws inferences for the development of the dairy sector in Ethiopia. We analysed the events following the three recent political regimes in Ethiopia, covering the period from the early 1960's to the present in identifying the phases of dairy development. The event history method examines technological innovation systems by mapping the interactions between system functions and structural elements over time. Past initiatives were analysed using content analysis to distinguish specific barriers to success in view of the fulfilment of the seven functions. The final outcome of the event analysis is a narrative on how different structural elements and innovation functions have shaped the dairy sector over time.

5.4. Results

This section presents the performance of the various functions of the Ethiopian dairy innovation system. In this section we analyse innovation system functions along with the failures in the structural elements. The results are presented according to seven themes, following the seven functions of innovation systems outlined in the literature.

5.4.1. Entrepreneurial Activities (F1)

This sub-section presents the entrepreneurial activities of smallholder farmers. Modern dairy farming in Ethiopia started in the early 1950s (Staal and Shapiro, 1996). In the early emergence of a modern dairy innovation system in Ethiopia, only a few large pilot dairy farms and milk processing plants were established in peri-urban areas to meet the growing demand for liquid milk in Addis Ababa (Ahmed et al., 2004). In the beginning, relatively successful applications of dairy technologies and the emergence of dairy-related businesses were encouraging. However, these successes were limited in scope only to large farms in peri-urban areas and had limited impact on overall productivity of the dairy sector (Staal and Shapiro, 1996). The majority of smallholder livestock producers were left out of technology and market driven dairy development (Ahmed et al., 2004; Tegegne et al., 2010).

During the ‘Military Coordinating Committee’ (Derg) socialist regime (1975-1991), private property was outlawed, and most private dairy farms were nationalised (Ketema, 2000). Nationalised private farms suffered from mismanagement and operational inefficiencies that led to abrupt disruption of dairy production in peri-urban areas. The Derg regime tried to develop the dairy sector using producers’ cooperatives and did not engage with smallholder farmers that were not cooperative members.

Since 1991, The Ethiopian People’s Revolutionary Democratic Front (EPRDF) regime has been encouraging smallholder dairy development through policy reforms and technology scaling up approaches. Despite many years of efforts, however, we observed only very few farmers that keep crossbred dairy cows and few dairy cooperatives engaged in milk marketing during our field work. The majority of farmers in the study areas are subsistence-oriented farmers. For example, one key informant pointed out that:

> “Livestock production in the district has been subsistence-oriented and animal husbandry practices use low external inputs. Farmers lack market knowledge and do not approach farming as a business. Smallholder farmers are typically poor and reluctant to engage in commercial dairy or beef.”

Various explanations have been put forward for smallholders’ reliance on subsistence-oriented animal husbandry practices and their inability to take advantage of productivity gains resulting from the use of agricultural technologies. Some researchers argue that the poor response of smallholders to promising economic opportunities and profitable production techniques could be due to issues beyond their control rather than lack of entrepreneurial capacity (De Janvry et al., 1991). They contend that prevailing unfavourable socio-economic conditions and political environment are insoluble for smallholders to overcome on their own. For example, smallholders find it difficult to secure credit for technological inputs with large up-front costs. Moreover, they lack information about the benefits of novel technologies, which makes it risky to invest. Technology purchase and use could be further limited by weak supply chains, missing infrastructure (e.g. roads or electricity) and uncertain property rights (Barrett et al., 2010).

Other scholars provide cultural and social explanations for the alleged poor entrepreneurial capability of smallholders (Bernard et al., 2014). They argue that smallholders in Ethiopia often do not make investments, even when returns are high, because they have low aspirations. Historically, Ethiopians become accustomed to maintaining hierarchical relationships with ‘god’ and the authorities (Lefort, 2012). These historical relationships have led to smallholders accepting man-made adverse circumstances as natural. A popular saying that exemplifies culturally embedded stereotypes states:

> “We were destined to be in the current state of affairs at birth. There is little we can do about it. So let us be content with the current state and pray that ‘god’ forbids the worst.”

This saying makes it sound as if their predicament is the will of ‘god’ and no one has the capacity to change it. It stems from the systems of beliefs, norms and values instilled by historical ruling elites in order to justify the status quo as natural or normal and to ensure continuity of the rulers’ domination over the majority smallholders (Davies, 2008). Therefore, the low entrepreneurial capacity of smallholder farmers seems to be linked to socio-economic, cultural and political underpinnings.

5.4.2. Knowledge development (F2)

In the last decade, Ethiopia is one of the few countries in sub-Saharan Africa (SSA) which has fulfilled its commitment to providing the funding needed for agricultural research programs in alignment with The Comprehensive Africa Agriculture Development Programme (CAADP) framework (Beintema and Stads, 2014). The country has made appreciable progress in human resource capacity development and has generated valuable research outputs needed to accelerate agricultural growth. Investments in agricultural Research and Development (R&D) and human resource development have increased since the early 1990s in Ethiopia (Beintema and Stads, 2014) . The gap in skilled manpower is gradually narrowing. In the last few decades, national and international agricultural research organisations in Ethiopia have made important contributions to the development of technologies in animal genetics, animal feeding and animal healthcare. Nevertheless, the focus of the research system has been largely limited to the development of technologies. Klerkx et al. (2012) argued that to promote innovation, research must be effectively linked to other actors (such as farmers, input providers and processors) in the innovation system. However, little attention has been given by the research system to the organisational innovations needed to allow technologies to spread in the livestock sector (Beintema and Stads, 2014). Despite the successes in technology generation, the agricultural research system seems to have failed to generative alternative organisational and institutional innovations that facilitate engagement of actors in the value chain. This could be linked to the so-called reflexivity failure. Focus group discussants and key informants also affirmed that there are adequate scientific capacity and agricultural technologies that can enhance livestock productivity in the country. However, they raised concerns regarding the competence and motivation of the personnel holding management positions in some research organisations. Focus group discussants and key informants also claimed that lengthy bureaucratic processes in government offices, regular interference of political officials on everyday operational decisions, and poor coordination of activities between different departments are widespread in the current regime. For instance, key informants described the competence and motivation problems of researchers as follows:

> “Senior researchers are less motivated because of the politicisation of the research system, low salaries and inadequate funding. Junior researchers lack the necessary expertise to conduct quality research due to limited opportunities for further training and lack of coaching by senior researchers.”

Some researchers also note that:

> “…bureaucracy is a major constraint to doing research. The procurement process is so cumbersome that it is difficult to buy supplies in time. The purchasing department is concerned only with controlling the budget rather than facilitating timely release of the budget for research.”

In sum, the country has made valuable progress in terms of allocation of funding for strategic agricultural research programs, improving technical capacity of researchers and generation of biophysical technologies but there are some deficiencies in management and in the application of systems approaches.

5.4.3. Knowledge diffusion (F3)

The Ethiopian Ministry of Agriculture, with offices at regional and district level, has a mandate to provide technical training and extension services to smallholders. Driven by the imperative of stimulating smallholder agricultural growth, Ethiopia has established the largest and fastest growing agricultural extension programme on the continent. The nation has some 60,000 agricultural extension officers, constituting as much as 25% of the overall extension manpower on the continent (Berhanu and Poulton, 2014). Even though the Ministry of Agriculture has the structures and reach, the key informants complained that the quality of extension service has been inadequate mainly because the extension agents spend a lot of time in non-extension activities at the expense of their regular job. For example, extension agents are heavily engaged in collection of loan repayments and organizing political meetings for local politicians around election times (Berhanu and Poulton, 2014; Cullen et al., 2014). Furthermore, the livestock extension system has been disproportionately influenced by livestock technical experts whose focus is on providing technical solutions to breeding, feeding and health constraints with little attention to organisational requirements of the innovation process in the livestock sector. Such a technology supply-push approach is aimed to create a flow of information and knowledge through a chain linking agricultural research, through subject matter specialists, village level extension workers and contact farmers, to ultimate users (Berhanu and Poulton, 2014). The linear extension paradigm implies a policy coordination failure that fails to embrace a more holistic, participatory model of knowledge diffusion.

Focus group discussants and key informants acknowledged the presence of a considerable number of actors in knowledge institutes and NGOs. However, interaction among relevant actors in the agricultural value chain is limited because of different perceptions among actors regarding objectives, assumptions, capacities, or lack of trust, indicating the presence of “directionality failure” (Ayele et al., 2012). Lately, lack of linkage between research, extension and farmers has been recognised as one of the problems in the Ethiopian agricultural research and extension system. There have been a few promising national and international efforts towards systems approaches for agricultural development in Africa whose lessons could be used as a springboard to explore potential interventions to overcome the constraints. Gradually, the trends in configuration of actors is shifting from limited actors in the government to multiple stakeholders such as international and national research and development organisations, small and medium-sized private dairy farms, dairy cooperatives, specialised milk transporters and processors and supermarkets (Jaleta et al., 2013). Since 1986, efforts have been made to harmonize interrelated institutional roles and establish functional linkages. A few linkage platforms implemented include Research Extension Liaison Committee, the Research-Extension-Farmer Linkage Advisory Council, and the Agriculture and Rural Development Partners Linkage Advisory Council (Ludi et al., 2013). Moreover, there have been a few initiatives piloting participatory approaches for agricultural development in Ethiopia such as participatory innovation development approaches, innovation platforms, dairy hub business models and integrated private input and service providers.

5.4.4. Guidance of the search (F4)

Officially government policies and strategies in Ethiopia have been oriented towards the promotion of agricultural growth and food security for smallholders. Particularly, the current government has made smallholder agriculture a priority for development through the Agricultural Development Led Industrialisation (ADLI) strategy (Dorosh and Mellor, 2013). The ADLI strategy had the aim to generate surplus agricultural output by using technological inputs on smallholder farms, registering varying degrees of success. Since 2011, the government has been implementing the Five Year Growth and Transformation Plan (GTP) and Agricultural Growth Program (AGP) (Dorosh and Mellor, 2013). The intention of the GTP and AGP programs is too narrow the gap between highly productive farmers and low performing farmers through a scaling-up strategy (Admassie and Abebaw, 2014). While the policies appear suitable for technological change and innovation, adoption of improved technologies remains low among smallholder farmers and productivity growth has not yet been realised (Dorosh and Mellor, 2013). However, limited recognition has been given to smallholder dairy production as a means of livelihood for the poor and the potential of livestock for poverty reduction (Ahmed et al., 2004). For many years, the livestock sector in Ethiopia was led by a directorate under the Ministry of Agriculture. Such a structural arrangement led to minimal focus on the provision of resources and operationalization of strategies specifically devoted to livestock. Since 1991, the current regime has focused on the dairy development through successive policy reforms (e.g., ADLI and GTP) (Admassie and Abebaw, 2014). In 2013, the Ethiopian government established the State Livestock Ministry within the Ministry of Agriculture. In 2014, the State Livestock Ministry launched a Livestock Development Master Plan that incorporates detailed directives including the amount and type of investment needed to boost the productivity of the livestock sector in Ethiopia (Ethiopian Radio and Television Agency, 2014). However, the function of the government has been limited to provision of 'public goods' narrowly defined as provision of physical infrastructure (primarily roads and telecommunications), agricultural research focused on generation of technologies and dissemination of information about these technologies, market regulation and the provision of a generally stable macroeconomic environment. As regards to non-state actors, there are recent efforts with 'innovation platforms' championed by various research and development actors, which could provide opportunities for joint vision creation and coordination of different structural elements of innovation systems. Furthermore, work is underway to enact Ethiopian Dairy Board legislation under the auspices of State Ministry of Livestock.

5.4.5. Market formation (F5)

The demand for dairy products is increasing in Ethiopia in response to increasing population, urbanisation and rising income. Nevertheless, farmers may struggle to make a profit from dairy due to poorly functioning input and output markets. During our field visits, we could not find private enterprises involved in input and service provision in the dairy sector, except a few private veterinary drug stores in small towns that sell tablets and provide veterinary services to farmers. Inadequate supply of improved breeds of dairy cows and milk collection points were also indicated by Ayele et al. (2012) as one of the major constraints to dairy development in Ethiopia. Focus group discussants in the study areas also identified the absence of farms that raise and sell improved breeds of dairy cows as a major constraint to dairy development. The discussants indicated that government artificial insemination (AI) and veterinary services are not effective. In Ethiopia, markets for dairy products are very thin and own-consumption shares are very high (Hoddinott et al., 2014). In rural areas dairy farmers have very little access to urban fluid milk markets and milk is often processed into local butter. Only a small proportion of fluid milk produced by smallholders is collected, packed and sold to consumers by dairy processing plants and marketing enterprises. According to the key informants, the cooperatives are mainly involved in collecting and retailing milk and the majority of them do not provide the complementary inputs and services needed in dairy production (Duncan et al., 2013). As Jaleta et al. (2013) argue that milk marketing cooperatives could help in reducing marketing costs and attracting buyers demanding bulk purchase at a lower average unit cost. The Government of Ethiopia has made efforts to link smallholder farmers to the urban fluid milk value chain through establishment of dairy cooperatives in the past. However, such efforts were not accompanied by complementary improvement in the quality of the social, economic and political environment that provide incentives to the emergence of new dairy enterprises. For example, the livestock sector has not been the focus of incentives, which could have included favourable access to land and loans, duty-free privileges, tax holidays and creation of niche markets or minimum consumption quotas (Staal et al., 2008).

5.4.6. Resource mobilisation (F6)

Historically, livestock development projects and programs in Ethiopia have been financed by donors, who have no long term commitment (Tegegne et al., 2010). The current government's policies and strategies in Ethiopia are officially oriented towards the promotion of agricultural growth and food security for smallholders. For example, Ethiopia is one of the eight countries in Africa, which meets the target of allocating an average of 15% of the government budget for agricultural development (Fan et al., 2009). As Berhanu and Poulton (2014) show, the budget allocated for agricultural development may not be spent wholly for provision of extension services as paid extension workers spend a large proportion of working hours in non-extension activities.

Ethiopia's development has been held back by underdeveloped infrastructure such as low road access (Foster and Morella, 2011). Lack of infrastructure drives the gap between the prices that farmers receive for their output and the market price, lowering the profits associated with underdevelopment of the dairy sector. By raising the fixed cost of distribution, poor infrastructure lowers profits for farmers and can further depress the take-up of new technologies (Jayne et al., 2010). In recent years, however, Ethiopia has improved its infrastructure significantly and its infrastructure indicators compare favourably with other low-income countries. It has launched an ambitious investment program to upgrade its network of trunk roads and to establish a modern funding mechanism for road maintenance. Ethiopia has spent more than $3.6 billion on road construction in the past 10 years. As a result, the road network has increased from 20,000 km in 1991 to over 48,793 km in 2010 (Foster and Morella, 2011). Although Ethiopia has made appreciable improvement in power development in recent years, the country still has one of the most underdeveloped power systems in SSA. Notwithstanding the recent government's investment in the mobile telephone sector, coverage of Information Communication Technology (ICT) services in Ethiopia is still one of the lowest in Africa (Foster and Morella, 2011).

5.4.7. Creation of legitimacy (F7)

The policy instruments and operational procedures employed for dairy development since the 1950s reflect the socio-political philosophy of successive regimes. The main thrust of dairy development policies during 1950s -74 was on improving commercial dairy production in selected areas of the country, especially around Addis Ababa (Ahmed et al., 2004). The majority of smallholder livestock producers were left out of technology and market driven dairy development. The Derg regime tried to develop the dairy sector using producers' cooperatives. However, cooperatives were turned into government and political tools rather than instruments for socio-economic development. Politicisation of the cooperatives distorted and stifled the role they could play in promoting production and marketing (Staal et al., 2008). Since 1991, there has been great attention to livestock development as demonstrated by the recent establishment of the State Livestock Ministry. However, there seems to be a policy coordination problem in that the government's objective of stimulating agricultural growth is thwarted by stifling bureaucratic processes, poor public service

Table 3. Evaluation of structural elements of dairy technological innovation system in Ethiopia

Time line	Structural elements			
	Actors	*Institutions*	*Interactions*	*Infrastructure*
1950s -74	Dairy production dominated by smallholders farmers, Some key actors such as knowledge institutes, input suppliers, civil society were missing	Exploitive institutions, lack of supportive policy to smallholder farmers in dairy development initiatives	No policy framework for interactions between relevant actors	Lack of roads, electricity & telecom coverage, lack of R&D capacity, underdeveloped dairy supply chain
1974-91	Dairy production dominated by smallholders, lack of private input and service providers, weak knowledge institutes and civil society	Ineffective institutions exercised through nationalisation of private farms, stringent regulation of private dairy farms, imposition of production quotas and regulation of agricultural product prices	Poor interaction between different stakeholders	Limited road, electricity & telecom coverage, limited R&D capacity, underdeveloped dairy supply chain, limited government resource to livestock sector
1991-present	Dairy production dominated by smallholders, shortage of input and service providers, limited capacity in knowledge institutes and civil society	Lack of well-defined property rights and weak enforcement of existing rules and regulations	Limited commitment to harmonize interrelated institutional roles and establish functional linkages	Limited road, electricity & ICT coverage, limited R&D facility, underdeveloped dairy supply chain

delivery and corruption (Berhanu and Poulton, 2014). As Cullen et al., (2014) argue power relations and underlying interests, incentives and ways of doing things are central to development project effectiveness and can hinder development. Therefore, available evidence indicates that policies and accompanying dynamics of interest, influence and power relations influence legitimacy creation to the dairy sector in the country.

5.5. Analysis and discussion

5.5.1. Structural-functional analysis of the dairy innovation system in Ethiopia

Based on the findings presented in previous sections, this section couples the absence or weaknesses of each function with the systemic problems in the four structural elements to help to explain the slow development in the dairy sector in Ethiopia (Table 4).

The analysis in Table 4 identifies the weak links in the dairy value chain deterring the uptake of technologies and dairy development. The systemic failures in the innovation system have blocked the development of innovation functions such as entrepreneurship, knowledge

Table 4. Systemic problems causing weakness or absence of the functions in the Ethiopian dairy sector

Innovation function	Observed weakness in innovation functions (missing/weak)	Systemic failure (reasons why a system function is missing or weak)	Type of systemic failure
Entrepreneur-ship	• Majority of farmers practice subsistence farming • Few farmers own high grade dairy cows • Negligible private sector investment in the dairy sector	• Smallholder farmers lack the capacity to identify opportunities and articulate their strategies • Members of small scale dairy enterprises are composed of persons with low levels of education	• Missing actors, capability failure, institution failures • directionality failure, demand articulation failure
Knowledge development	• Education and research institutions underdeveloped until 1990s • Inadequate knowledge on institutional arrangements for coordinating complementary sources of knowledge • Little attention given to organisational innovation	• Narrow research focus on technology generation and dissemination • Research system lacks the capacity to analyse the bottlenecks in dairy value chains • Weak research capacity in socio-economics	• Missing actors, capability failure, hard and soft institution failures, Interaction failure, merits in increased manpower training
Knowledge diffusion	• Adequate knowledge on livestock technologies is not accessible to farmers • Extension focus on dissemination of scientific knowledge and technology only • Smallholders left out of dairy development initiatives until 1980s • Few and weak dairy cooperatives	• Inadequate capacity in public extension system for knowledge diffusion • Lack of coordination between agricultural departments • Budgetary constraints for extension agents to run activities • Extension agents overloaded with multiple activities	• Hard and soft institution failures, interaction failure

(Continued to the next page)

Innovation function	Observed weakness in innovation functions (missing/ weak)	Systemic failure (reasons why a system function is missing or weak)	Type of systemic failure
Guidance of search	• Poor public service delivery, prevalence of corruption, uncertain property rights and poor law enforcement • Limited access to land, loans, duty-free privileges, tax holidays, etc. • Uncertainty among farmers about potential demand for their product	• Policies failed to set clear vision, objectives and targets for livestock sector development • Nationalisation of private farms and stringent regulation on private dairy farms during the Derg regime had negative effects • Lack of demand-pull policy instruments to induce entrepreneurship among smallholder farmers • Poor road networks & telecommunication	• Capability failure of existing actors , institutional, interaction and infrastructural failures • Directionality failure, demand articulation failure
Market formation	• Coordination failure hindering delivery of inputs and services and collection of milk from unorganised smallholders in rural areas	• Shortage of actors who raise and sell dairy heifers and provide artificial insemination and veterinary services and transport and sell milk	• Missing actors, market failure, institution failures, interaction failure
Resource mobilisation	• Most livestock development programs and projects are financed by donors, meagre government R&D funding for the livestock sector	• Most livestock projects were financed by donors • Inadequate funding	• Physical infrastructure failure, shortage of financial resources, limited research capability
Creation of legitimacy	• Advocacy and interaction among farmer organisations, professional associations, researchers, policy makers is weak	• Weak connectivity between actors • No legal framework for interactions between relevant actors	• Missing actors, interaction failure, capability failure, reflexivity failure

Note: This analysis is based on the framework proposed by Wieczorek and Hekkert, 2012.

diffusion, market formation and creation of legitimacy. This shows that the failures in structural elements underpin the underdevelopment of innovation functions, as Negro et al. (2012) also found. A weakness in one of the innovation functions in turn would have a knock-on effect on other functions which eventually cripple the entire dairy value chain. The systemic imperfections and associated weaknesses in innovation functions in turn constrained farmers from taking advantage of new technologies and economic opportunities in the dairy sector. From the analyses presented above it follows that underdevelopment of the dairy sector in Ethiopia could be explained by the weaknesses in innovation functions as well as systemic failures such as shortage and limited capacity of actors, institutional and interaction failures.

5.5.2. Potential interventions to address systemic imperfections and functional failures

Subsistence-oriented smallholders in mixed crop–livestock systems account for the larger share of human and livestock populations and produce the largest share of Ethiopia's food production (Herrero et al., 2010; Oosting et al., 2014). Recognising the fact that persistence of subsistence-oriented livestock production and underdevelopment of the smallholder dairy sector in Ethiopia stem from unfulfilled innovation functions and underlying systemic failures helps us understand how best to address them. The first logical step is reviewing efforts made in the past towards identifying and acting on system failures and functional weaknesses in smallholder livestock production in SSA whose lessons could be used as a springboard to explore potential interventions to overcome the constraints summarised in Table 4. Various organisations have piloted farmer field schools (FFS) as an alternative approach to enhance participatory agricultural technology development and knowledge diffusion in Ethiopia (Davis et al., 2012). More recently, the Nile Basin Development Challenge Program has used innovation platforms to facilitate interactions among stakeholders and so enhance knowledge exchange (Cullen et al., 2014). The Improving the Productivity and Market Success of Ethiopian Farmers (IPMS) project has tried to empower the extension system by establishing knowledge centres in the districts with a view to improving knowledge diffusion (Tefera et al., 2011). Similarly, Stichting Nederlandse Vrijwilligers (SNV), has been piloting a dairy hub business model in Ethiopia to facilitate market development and foster entrepreneurship (Visser et al., 2012). CNFA, a Washington, D.C.-based international development organisation, is piloting a Commercial Farm Service Program in Ethiopia to enhance smallholder's access to agricultural inputs, services, technologies and output markets (Miklyaev and Jenkins, 2013). In a similar vein, Promoting Local Innovation (Prolinnova), a Netherlands-based NGO, has been working to provide a favourable environment for stakeholder interaction and drawing on farmer's local innovation processes to enhance agriculture and natural resource management (Fenta and Assefa, 2009).

Building on existing lessons, here we suggest a range of interventions to strengthen the weak functions in dairy innovation system such as entrepreneurship, knowledge diffusion, market formation and legitimacy creation. For example, the critical shortage of crossbred dairy heifers that resulted mainly from the weaknesses in entrepreneurship and market formation could be tackled by fostering establishment of private calf nurseries and heifer rearing businesses. The weakness in knowledge diffusion could be improved by linking the extension service with modern ICT tools. Allocating adequate budget to extension agents at district and village levels and relieving extension workers of work overload from activities beyond their stated mandate could enable them to do their extension activities more effectively and so enhance knowledge diffusion. The problems in input and service delivery resulting from ineffective knowledge diffusion and weak market formation could be addressed by fostering establishment of private input and service delivery systems (Kilelu et al., 2011; Poulton et al., 2010). The problem of collecting milk from spatially dispersed dairy producers which stems from weak entrepreneurship and poor market formation could be improved by establishing dairy hubs that link smallholders to urban milk processors and retailers (Jaleta et al., 2013). Moreover, the dairy hub model could be linked to school feeding programmes, which would create local markets for milk. The other option to address market constraints in the dairy value chain would be to nurture the establishment of contractual arrangements between large agribusinesses and smallholders (Kilelu et al., 2011; Miklyaev and Jenkins, 2013). Large agribusinesses could provide smallholder farmers with access to products, services and markets, which could significantly improve their productivity and income. The problems in legitimacy which arises from systemic failures such as cumbersome bureaucratic procedures, poor law enforcement and corruption could be tackled through measures directed towards improving public service delivery, better law enforcement, increased protection of property rights and corruption control. Strengthening the relatively weak “Ethiopian National Dairy Forum” could help address the problem of legitimacy creation. Moreover, policy interventions which facilitate favourable access to land and loan, duty-free privileges and tax holidays could nurture development of innovation functions and foster dairy development in the country.

5.6. Conclusion

This study was driven by one central research question: how the failures in innovation system elements and unfulfilled innovation functions in the dairy value chain have influenced adoption of technologies and dairy development in the Ethiopian highlands.

Using a coupled functional-structural analysis of innovation systems framework and historical evidence, we analysed innovation system failures and functional imperfections in smallholder dairy production systems. The analysis show that missing actors, limited capacity of existing actors, inadequate infrastructure, limited interactions between actors, insecure property rights, stifling bureaucratic processes, corruption and poor coordination of functions along the value chain are all associated with low adoption of technologies and underdevelopment of the dairy sector in the Ethiopian highlands. Past government policies and strategies have given strong emphasis to technical innovation, and have failed to link technical innovation with relevant institutional innovations that make dairy value chains functional. The emphasis has been on the supply of technologies, and the policies that stimulate the demand for technologies have received little attention. As a result, the smallholder dairy sector has largely failed to establish functioning dairy value chains that can provide access to inputs and services at affordable prices and efficiently move products to markets. The analysis also shows that there is no a single, all-encompassing intervention that addresses the problems in the dairy sector. Therefore, the dairy sector development could benefit from current efforts aimed at enhancing systemic interaction in the agricultural innovation system. A broad policy message is that coordination mechanisms need to be given a much more prominent place in policy thinking. A range of organisational interventions, such as dairy hubs and innovation platforms could begin to overcome the different constraints identified in the dairy value chains. Moreover, dairy development programs in Ethiopia would have a better chance of success if they target farmers who have better resource endowments and are connected to better-functioning value chains in the short and medium term. The interventions, including the ones suggested in this paper, also require a supportive investment in rural infrastructure and improvements in the overall socio-economic and political environment for farmers and related businesses. The general recommendation for agricultural researchers is that they need a combination of diverse kinds of knowledge and understanding in order to unpack the complex and interrelated constraints in agricultural systems. Further research is required on alternative institutional arrangements that coordinate stakeholders, facilitate supply of technological inputs and services and develop product markets at scale. The coupled functional-structural framework appears to be a promising framework in identifying the bottlenecks and success factors in the smallholder dairy innovation system in developing countries.

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Chapter 6

General Discussion

6.1. Introduction

The overall objective of this study was understanding the factors affecting adoption of technologies that enhance the productivity of livestock production and water use efficiency in the Ethiopian highlands, with particular emphasis on dairy production. The study was intended to deepen the understanding on the role of factors at the levels of farm households, value chain and macroeconomic institutions and policies on farmers' technology adoption decision. The study employed an interdisciplinary approach to analyse micro, meso and macroeconomic constraints that affect adoption of technologies in livestock production. The aim of the general discussion is to integrate insights from the different chapters of the thesis to address the central research objective of the thesis. This chapter comprises three sub-sections: summary of main findings of individual papers, reflection on major findings and suggestions for development interventions, policy and future research.

6.2. Summary of main findings

This sub-section highlights the key findings of the preceding chapters that help address the central research objective of the thesis.

Chapter 2 dealt with characterisation of farming systems and identification of factors that affect livestock water productivity (LWP) in mixed crop livestock production systems. We quantified LWP for various farms in mixed crop-livestock systems and explored the effect of household demographic characteristics and farm assets on LWP, using analysis of variance and multilevel mixed effect linear regression. Results show considerable variation in LWP within and among farming systems and wealth categories. Farmers in the wheat-teff farming systems at *Jeldu* had more family labour than farmers in other systems. Farmers in the wheat-teff farming systems at *Jeldu* and in the teff-millet and maize-sorghum farming system at *Diga* had more land than farmers in other systems. Furthermore, the total value of grain products, the amount of rainwater evapotranspired in livestock feed production and LWP were different among farming systems. LWP was relatively high in the teff-millet and rice-pulse farming systems at Fogera. The average family labour per household was higher in better-off and medium wealth categories as compared to poor household categories. The average land holding was higher for households in better-off followed by medium wealth categories. The area under food-feed crop production and area under grazing among wealth categories followed the same pattern as for the total land holding. The average livestock and oxen holdings were higher in better-off and medium wealth categories than in the poor household categories. Average livestock holding per unit of land were also higher in better-off than in poor households. The amount of water depleted for feed production, the value of livestock outputs/services and LWP were higher for better-off and medium household categories than for poor household categories. Regression results showed that age of the household head, the size of livestock holding and availability of family labour affected LWP positively.

The primary aim of **Chapter 3** was to understand why many farmers in Ethiopia have not adopted dairy technologies, taking Kenya as a comparative case study. Adopters and non-adopters of dairy technology were compared based on variables describing ownership of farm resources and access to markets and information. Results show a higher fraction of sample households in Kenya kept improved dairy breeds, cultivated improved forages, used artificial insemination and veterinary services, and participated in dairy cooperatives than their counterparts in Ethiopia. The difference in the level of technology adoption between sample farmers in the two countries was attributed to the better market development for dairy products in Kenya than in Ethiopia. Farmers who adopted dairy technologies had more family labour, reside closer to markets and had better access to information compared to non-adopters. The results indicate that dairy technology adoption increases with increase in farm resource endowment and level of market development.

Chapter 4 investigated the impact of adopting dairy technologies on household nutrition and income using propensity score matching and a sample treatment effect estimator. Results show that adopting crossbred dairy cows and improved forages increased household nutrition and income. The comparison of adoption impact estimates by propensity score matching and the sample treatment effect estimator indicated that unobservable variables have influence on technology adoption and impacts, which suggests that smallholders are heterogeneous in initial resource ownership conditions and in individual characteristics such as entrepreneurial ability, motivation or ingenuity, attitude towards risk and networking ability. The variation in such initial resource ownership status and in individual characteristics may explain part of the variation in adoption of dairy technologies and their impacts.

Chapter 5 examined the influence of macroeconomic institutional and policies on adoption of technologies in the dairy sector. A functional-structural analysis framework, adapted from innovation systems approaches, was used to analyse the historical evolution of the macroeconomic institutional environment and policies which have implications for dairy intensification. Results show that systemic failures (problems in structural elements) such as the absence of key actors, limited capacity of existing actors, institutional problems, poor interaction among actors and inadequate infrastructure have been prevalent in Ethiopia. Some of the institutional problems include cumbersome bureaucratic processes, insecure property rights, rigid and restrictive procurement regulations, failures of accountability in the public service delivery chain, corruption, unclear and ever-changing government regulations, multiple protection measures that resulted in high import costs of technological inputs and poor law enforcement. Examples of infrastructural problems include poor rural roads and unreliability supply of water and electricity. Out of the seven innovation functions studied, the analysis showed that entrepreneurship, knowledge diffusion, market development and legitimacy creation have been particularly weak. In the analysis, the chapter illustrated how historical institutions and policies matter for technology adoption and dairy development.

6.3. Reflections on major findings

This section starts by describing the context in which smallholders in the Ethiopian highlands operate. This context provides the basis for the reflecting on the major findings about technology adoption by smallholders.
In the Ethiopian highlands, most farmers are smallholders, who practice low-input, rain-fed agriculture, which results in low levels of production. The majority of farmers practice subsistence agriculture for sustenance of their families. The households in the study area derive their livelihoods from crop and livestock production, and off-farm activities. Crop

production is the main economic activity, which meets the larger share of annual food needs for the household. In a typical year, a household will grow staple cereals, pulses and some vegetables and fruit. Livestock production is an integral part of the livelihood activities pursued by the households (Alemayehu et al., 2012). The animals are used as sources of milk, meat, cash income, draught power, manure, insurance and as a store of wealth. A household derives some income from the sale of livestock products and live animals. Households are also involved in off-farm activities, such as petty trade and other income generating activities (Bezu et al., 2012). The primary objective of households in the Ethiopian highlands is ensuring household food security and fulfilling the need for cash income required to cover family expenses (e.g. expenses of clothes, school fees, funerals, fertilizer loan repayment, weddings, membership fees to local organizations and religious donations) (Alemayehu et al., 2012). A household as a family unit makes decisions about resource allocation to agricultural and off-farm activities, consumption of outputs, savings and investment.

Typical household resources include family labour, a small area of farm land, livestock assets and basic farm implements (Kebebe et al., 2014). A household uses the income derived from crops, livestock and off-farm activities to cover family expenses and invests the residue for improvement of crop and livestock production. When annual harvest is low, due to bad weather or other calamities, households struggle to feed the family throughout the year and to cover basic expenses (Amede et al., 2009; Diogo et al., 2010; Molden et al., 2010; Peden et al., 2009). To meet food security and income needs, households aspire to increase the productivity of crop and animal production. The use of modern agricultural inputs, such as improved breeds of dairy cows and cultivation of improved varieties of crops is often seen as a pathway to increasing agricultural productivity and resource use efficiency. However, adoption of the technologies has been low, despite numerous efforts to disseminate the technologies in the past (Ayele et al., 2012; Deneke et al., 2011). This raises the question as to why the majority of smallholders not adopted agricultural technologies in the Ethiopian highlands. What does adoption of dairy technologies entail? In what follows, the role of different factors at the level of household, value chain, institutions and policies on technology adoption are assessed by taking insights from individual chapters.

A household requires adequate capital to purchase technological inputs (cross-bred dairy cows, feed supplements, veterinary medicine, construction of animal sheds, etc.), sufficient family labour to manage the dairy farm, and sufficient land so that improved forages do not compete unduly with staple crop production, before considering adoption of improved technologies (Ayele et al., 2012; Duncan et al., 2013b). This argument is supported by the findings of **Chapter 3**, which indicated that adopters tend to be those who have more key farm resources such as family labour, livestock assets and mobile telephones, relative to resource-poor farmers. These results suggest that farm resource endowments partly explain why some farmers adopt technologies, whereas others do not. The result corroborates previous research findings that noted that resource ownership affects adoption of dairy technologies by smallholders (Abdulai and Huffman, 2005; Franzel et al., 2001; Gebremedhin et al., 2003; Staal et al., 2002; Tefera et al., 2014).The relationship between adoption of technologies and resource endowment can be further illustrated by looking at the mechanisms by which specific farm resources affect adoption of technologies. Previous studies in developing countries on the relationship between family labour and technology adoption have shown that smallholders may not have sufficient cash to hire labour or that markets for hired labour may not exist in rural settings. Hence, family labour supply is crucial in decisions to engage in labour-intensive enterprises such as dairy and in the adoption of agricultural technologies that are labour intensive (Feder et al., 1985; Gebremedhin et al., 2009; Staal, 1995). Therefore, the positive association of technology adoption with family labour appears logical for smallholders in the Ethiopian highlands. The positive association between technology adoption and ownership of physical assets such as livestock is also well-documented (Dercon and Christiaensen, 2011; Shiferaw and Holden, 1998). In rural Ethiopia, where credit services are unreliable, wealth accumulated in livestock provides options to generate the cash needed for investments in livestock technologies. Similarly, wealth accumulated in livestock reduces the risk associated with new technologies, which may enhance investments in technologies. Therefore, the positive relationship between livestock assets and technology adoption seems plausible. Furthermore farmers need to know that new technologies are available, to understand their potential benefits and to know how to apply such technologies effectively before they adopt. Hence, the positive relationship between technology adoption and access to communication mechanisms such as mobile telephones is consistent with the notion that access to information (e.g. through mobile phones) is likely to facilitate technology adoption (Aker, 2011; Pannell et al., 2006).

Improved technologies need to lead to high net returns after covering all direct and indirect costs to justify their adoption by farmers. Some technologies which appear profitable at first sight may not be profitable when all direct and indirect costs under smallholder conditions are accounted for. This argument was partly supported by the differences in the welfare outcomes between resource-poor and resource-rich farmers in **Chapter 4**. Variation in the effect of dairy technology adoption impact on household nutrition and income due to potential bias arising from unobservable factors suggests that unobserved differences between households could have a strong influence on adoption and impact of agricultural technologies to different groups of farmers. The strong influence of unobservable variables on the impacts of technology adoption suggest that resource-rich households, due to their better initial resource endowment and superior individual characteristics, can overcome some of the direct and indirect costs associated with the adoption of technologies. Hence, resource-rich farmers have a comparative advantage over their resource-poor counterparts in technology adoption (**Chapter 4**). The results support the idea that lower than expected adoption by Ethiopian smallholders could relate to different groups of farmers having different potential benefits. The results of this study corroborates other findings which have shown that unobserved circumstances facing different groups of smallholders partially explain the difference in technology adoption and the variation in net benefits to agricultural technologies (Suri, 2011).

In addition to access to farm resources and potential benefits of the technologies, households require a reliable value chain that ensures access to the supply of technological inputs such as supplementary feed at reasonable price, reliable access to artificial insemination and veterinary services, a high quality extension service, access to credit, insurance and assured markets to sell milk before considering technology adoption (Bernard and Spielman, 2009; Jaleta et al., 2013). Moreover, smallholders require stable input and output prices, protection of property rights and reasonably well developed rural infrastructure (e.g., road, water, electricity and communications) (Hazell, 2013; Jaleta et al., 2013). The need for a reasonably well developed value chain was highlighted by the findings in **Chapter 5,** which showed that the development of innovation functions, such as entrepreneurship, knowledge diffusion, market formation and creation of legitimacy was hindered by the failures in structural elements of the innovation system. Results also showed that weaknesses in various innovation functions in turn had a knock-on effect on other functions in the dairy value chain, which eventually undermined adoption of technologies by smallholders. The channels by which underdevelopment of innovation functions appear to limit adoption of dairy technologies can be illustrated by taking some findings from **Chapter 5**. For example, it was found that a critical shortage of crossbred dairy heifers was mainly related to weaknesses in innovation system functions such as entrepreneurship and market formation. The problems in input and service delivery and the problems of collecting milk from spatially dispersed dairy producers resulted from ineffective knowledge diffusion and weak market formation. The problems in legitimacy of smallholder dairy stemmed from systemic failures, such as cumbersome bureaucratic procedures, poor law enforcement and corruption. These bottlenecks collectively raise transaction costs (e.g., the costs of information search, sourcing of technological inputs, searching for trading partners, negotiating deals, enforcing contracts, the need to bribe bureaucrats and lobby politicians) and systematically reduce the gains for poor farmers from adopting technologies (Hazell, 2013; Jaleta et al., 2013). The high transaction costs involved in accessing the technologies may lead to the cost of using technologies greater than the potential benefits gained from the technologies. The results support the notion that access to new technologies and effective institutions are key in stimulating technology-driven agricultural productivity (Barrett et al., 2010; Deneke et al., 2011; Djurfeldt et al., 2005; Dorward et al., 2004; Fan, 1991; Hounkonnou et al., 2012; Ruttan, 2002). These observations are also consistent with previous findings which argue that low technology adoption in Ethiopia could be ascribed to poor provision of key physical infrastructure (e.g. roads, electricity and water) and missing or incomplete value chains (Duncan et al., 2013a; Francesconi et al., 2010; Oosting et al., 2014). The above discussions show the direct and indirect links between macroeconomic institutions and policies and technology adoption by smallholders.

In sum, the findings in the empirical chapters underscore the notion that low adoption of the technologies that enhance the productivity of livestock production and water use efficiency stem from farmers' limited access to farm resources (**Chapters 2, 3 & 4**), differences in potential benefits of the technologies (**Chapter 4**), lack of effective and reliable value chains for inputs and outputs, inadequate physical infrastructure, and weak institutions and policies (**Chapter 5**). These findings show that smallholders have been subjected to multiple constraints. Given the multiple constraints at different levels within the dairy sector and the associated transaction costs facing smallholders in rural Ethiopia, the returns to investment in technologies may be too low to justify widespread adoption of the technologies. Therefore, smallholders are simply responding to the incentives and constraints inherent to their agricultural circumstances. In the absence of functional institutional mechanisms that offset these transaction costs, the avoidance of technically high yielding technologies by the majority of the smallholders and their continued reliance on subsistence-oriented animal husbandry practices may be a sensible choice. This observation is also consistent with the findings of other studies on the problems of smallholders in developing countries which have concluded that smallholders' unwillingness to adopt technologies are rational responses to the high transaction costs associated with adoption of the technologies (De Janvry et al., 1991; Kirsten, 2009; Otsuka, 2006; Schultz, 1964). Therefore, adoption of technically beneficial technologies has been suppressed by the lack of adequate incentives that justify widespread uptake of the technologies by the smallholders. Unless beneficial technologies are accompanied by simultaneous improvements in access to farm resources, input and output markets and measures to overcome policy and institutional barriers, large-scale technology adoption appears less likely.

In relation to the importance of using a multi-level approach emphasised in the introduction to this thesis, the results from micro-level quantitative studies in **Chapters 2 to 4** substantiate the premise that farm resource endowments provide part of the explanation for the variation in technology adoption and water use efficiency among farm households. The strength of micro-level studies was that the detailed quantitative data allowed application of statistical methods to generate a well-grounded evidence base for the argument. However, the quantitative methods could not fully unpack technology adoption determinants embedded in socio-economic circumstances and institutional settings. As argued in **Chapter 1**, the unexplained factors affecting technology adoption and water use efficiency could also be partly accounted for by constraints in macroeconomic institutions and policies. The analysis in **Chapter 4 and 5** helped to disentangle some of the channels by which macroeconomic institutions and policies affect technology adoption and water use efficiency in the livestock sector. Indeed, the empirical evidence supports the initial hypothesis that constraints to adoption of agricultural technologies could be better understood by studying adoption constraints at the levels of farm households, value chains and macroeconomic institutions and policies.

Recognising the fact that low technology adoption and persistence of a subsistence mode of production in livestock sector stems from low farm resource endowments, public goods deficits, absence of effective and reliable value chains for inputs and outputs and institutional and policy gaps helps us to focus on interventions that address these constraints. Now, it is worth exploring alternative interventions that could possibly relax the identified constraints.

6.4. Implications

6.4.1. Implications for development intervention

As noted in the preceding chapters, livestock development efforts in Ethiopia have been based on isolated interventions that deal with problems of feeding, breeding and animal healthcare at production level. However, such a piecemeal approach has not grown the sector in a substantial way for many years. Based on the results presented in preceding chapters, smallholder farmers appear not to use agricultural technologies because of the multiple constraints that prevent them from taking advantage of productivity and profit opportunities offered by the technologies. Therefore, adoption of technologies in the dairy sector requires interventions at production, storage, transportation, processing and marketing chains and at macroeconomic institutions and policies. Technology adoption in dairy sector requires improvement in entire dairy value chain and no single intervention seems adequate to trigger adoption of technologies and intensification of dairy production. The key challenge has been to address the widespread coordination problem in the dairy value chain. Programs that simultaneously address interrelated problems along the dairy value chain are required. The disappointment with the performance of public service delivery in the agricultural sector has prompted a search for alternative ways to involve the private sector in provision of services that were traditionally considered to be the preserve of public agencies (Poulton et al., 2010). A range of interventions aimed at facilitating public-private partnership (PPP) arrangements that could overcome the different constraints identified in dairy value chains are highlighted here. Public-private partnership arrangements could provide “win–win” solutions to the widespread coordination problems in the dairy value chain. For the smallholders, such programs could provide access to modern inputs, credit and market outlets. Private sector players could benefit from business opportunities as well as the incentives provided by the government in the form of tax breaks, loan guarantees and preferential tariff arrangements to offset some of the initial costs of initiating activities along value chains. For the government, such programs could boost investment, income and employment in the farm sector.

One type of PPP intervention to overcome some of the bottlenecks in the dairy value chain could be through improving the business environment for the private sector so that private businesses could flourish and cater for inputs and services at different nodes of the dairy value chain. For example, a critical shortage of crossbred dairy heifers in Ethiopia could be addressed by encouraging establishment of private calf nurseries and heifer rearing businesses. Establishment of integrated input and service distribution networks by the private sector could address the problems in the input and service delivery system (Kilelu et al., 2011; Poulton et al., 2010). The problem of collecting milk from unorganized smallholders could be overcome by establishing dairy hubs that link smallholders to processors and help urban milk processors to access milk produced by smallholders (Jaleta et al., 2013). Dairy hubs could enable spatially dispersed dairy producers, milk collectors, processors and other supporting businesses to increase milk production at the farm level, improve collection and logistics, and strengthen processing efficiency. Moreover, the dairy hub model could be linked to school feeding programmes to enhance societal benefits. Nutritional benefit of dairy consumption is a well-established fact. School feeding programmes promote children’s access to nutrition, health and education as well as helping to build the demand for locally produced and processed quality milk (Jabbar and Ahuja, 2011). Furthermore, coupling school feeding with awareness creation campaigns about the benefits of dairy consumption could raise local demand for dairy products. The conventional dairy cooperatives could also play an important role in providing some of the coordination functions needed to enhance farmers' access to input and output markets (Poulton et al., 2010). The other option to address the constraints in dairy value chain is nurturing establishment of contractual arrangements between large agribusinesses (e.g., FrieslandCampina, TetraPak, and Nestle) with smallholders. Another intervention that could help smallholders to access markets could be through innovative PPP arrangements that linked smallholders to supermarket chains (Francesconi et al., 2010). Still, technology-intensive dairy may not be a promising livelihood option for larger section of agricultural households in Ethiopian highlands. Interventions which facilitate the growth of other sources of livelihoods, such as off-farm activities, could be a promising option to the bulk of resource-poor agricultural households. To allow alternative modes and scales of production to emerge, new institutional and policy frameworks are required. This will be described in the next paragraph.

6.4.2. Policy implications

Science and technology can drive major breakthroughs in agricultural development, but social and economic barriers, such as weak institutions, can prevent potentially beneficial technologies from reaching the poor. To bring about social change, research findings need to be transformed into better policies and programs. The government has a positive role to play in stimulating dairy development by enabling markets to function well. On paper, most of the governments' existing policies and strategies in Ethiopia are officially oriented towards promotion of agricultural growth and food security for smallholders. Ethiopia, for example, is one of the eight countries in Africa which meet the target of allocating 10% of national budgetary resources for agricultural development (Berhanu and Poulton, 2014). However, the strategies appear to be biased towards financing rural infrastructure (e.g., roads, railways, water, electricity and communications) agricultural extension system, with less attention to improving the quality of service delivery. As the results in **Chapter 5** show, government offices are plagued with stifling bureaucratic hurdles, corruption and poor coordination between departments. In some cases the policies and strategies that support science, technology and innovation are not followed through as stated in policy documents. There is a need to concentrate both on building high quality institutions and on enforcement of existing ones. Civil service reform programs, including *gimgema* (re-evaluation), Business Process Reengineering and the Balanced Score Card, have been promising initiatives. The civil service reform programs, however, appear to be running out of steam and fading in recent years (Lemma, 2011). Commercialisation of agricultural technologies requires interventions beyond provision of common public goods and extension service. The policy agenda for agricultural development needs to be directed towards overcoming the widespread institutional barriers hindering smallholders and related agri-businesses from taking advantage of technological and market opportunities.

The role of agricultural development programmes needs to focus on improving the quality of the macroeconomic institutions and policies in addition to investment in rural infrastructure, and public research and extension. For example, favourable access to land and loans, duty-free privileges, tax holidays, improved public service delivery, corruption control, better law enforcement, increased protection of property rights and contract enforcement can improve adoption of technologies and foster dairy development. Building effective, transparent and accountable institutions lowers transaction costs, encourages trust, reinforces property rights and avoids the exclusion of sections of the population (e.g., resource-poor smallholders). Many of the policy issues raised in this discussion are not peculiar to dairy technologies but relevant to most technologies to increasing productivity of smallholder farming in Ethiopia.

6.4.3. Implications for future research

Given the results highlighted in the preceding sections, the important challenge is not only developing technologies but also understanding the contextual factors that facilitate or hinder their uptake. One of the limitations of this study is that adoption and impact was assessed using smaller numbers of dairy technology adopters vis-à-vis large number of non-adopters. This could limit the generalizability of the results from quantitative models across population. Methodological literature for fitting adoption and impact models in cases where there are a large number of non-adopters and few numbers of adopters seem underdeveloped. Methodological limitation of adoption and impact based on neoclassical economic models may be only part of the challenges for agricultural development researchers. A practical challenge is how to make alternative methods for adoption and impact assessment understandable to applied researchers. Therefore, future research which handles unbalanced datasets on adopters and non-adopters and which takes into account the influence of social, economic and political factors that underlie differential welfare outcomes could help validate whether the results in this study could be generalizable for majority of smallholder farmers in developing countries.

Another important message to future agricultural research is that it needs to shift research focus from developing new technologies towards assessing broader sets of institutional, social and political processes that have a bearing on technology uptake. The coordination problem is an area where we need more policy research, both to better understand the conditions under which coordination problems are severe and on the best institutional and policy interventions to fix the problem. It requires researchers and development professionals to design proactive engagement strategies with stakeholders to influence policies and programs. This calls for a shift of research focus from solely biophysical technology generation and dissemination towards research on social sciences: designing, prototyping and experimenting with alternative institutional arrangements that can effectively coordinate stakeholders, facilitate supply of technological inputs and services and develop product markets. In future research, the use of integrated frameworks and combination of quantitative and qualitative analysis could help analyse the bottlenecks in the dairy sector and identify effective intervention points to stimulate technical change in the country's livestock sector.

6.5. Key conclusions

- There was evidence of variation in livestock water productivity and in the uptake of dairy technologies within and among farming systems. The uptake of technologies was low in aggregate, but it was not uniformly low across all typologies of households.
- In general, farmers with more land, labour and livestock endowments and better access to markets and information adopted livestock technologies and recorded relatively higher household nutrition and income.

- While there is abundance of scientific and technical knowledge about livestock technologies, smallholders’ limited access to farm resources, lack of reliable value chains for inputs and outputs and weak institutions and policies have been hindering widespread uptake of the technologies.
- Macroeconomic institutional and policy factors appear to be more important determinants of technology adoption than household-level factors.
- Given that majority of smallholders have limited farm resources, unreliable value chains for inputs and outputs and ineffective institutions and policies, smallholders have no adequate incentives that justify widespread uptake of the technologies.
- Technology adoption requires a combined application of technological, institutional, and policy interventions.
- Understanding agricultural development problems requires a holistic insight in agricultural sciences, economics, innovation studies and political science among others.

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Summary

In response to population growth, rising income and urbanisation, the demand for livestock products, such as milk, meat and eggs is growing in Ethiopia. The growing demand for milk products offers opportunities for smallholders to realize better livelihoods. Whereas the growing demand for milk products in Ethiopia is widely recognised, the dairy sector has not been able to produce adequate milk to satisfy this demand, mainly due to low productivity of dairy animals. The national average daily milk yield from indigenous dairy cows is 1.9 litres per cow and even in the Ethiopian highlands, where this study was conducted, average daily milk yield is only around 2.3 litres per cow. The use of technological inputs, such as improved breeds of dairy cows and cultivation of improved forages, is often seen as a prerequisite to increasing livestock productivity and resource use efficiency in the smallholder dairy sector. However, adoption of such technologies has been low, despite numerous efforts to disseminate the technologies in the past. This poses a question as to why the majority of smallholders have not adopted livestock technologies in the Ethiopian highlands. The overall objective of this study was understanding the factors affecting adoption of technologies that enhance the productivity of livestock production and water use efficiency in the Ethiopian highlands, with particular emphasis on dairy production. The study was intended to deepen the understanding on the role of factors at the levels of farm households, value chains and macroeconomic institutions and policies on farmers' decision to adopt technologies.

Chapter 2 deals with characterisation of farming systems and identification of factors that affect livestock water productivity (LWP) in mixed crop livestock production systems. We quantified LWP for various mixed crop-livestock systems and explored the effect of household demographic characteristics and farm assets on LWP. Results show considerable variation in LWP within and among farming systems and wealth categories. Differences were found among farming systems with regard to labour and land availability, the total value of grain products, the amount of rainwater evapotranspired in livestock feed production and LWP. The overall average LWP in the study area was 0.21 US$ m^{-3}, whereas the highest LWP of 0.34 US$ m^{-3} was recorded in the teff-millet farming system at Fogera district and the lowest LWP of 0.13 US$ m^{-3} in maize-sorghum farming system at Diga. The average family labour per household, the total land holding, area under food feed crops and area under

grazing, and livestock and oxen holding were all higher in households of high and medium wealth category as compared to poor households. Regression results showed that age of the household head, the size of livestock holding and availability of family labour affected LWP positively.

The primary aim of **Chapter 3** was to understand why many farmers in Ethiopia have not adopted dairy technologies, taking Kenya as a comparative case study. Adopters and non-adopters of dairy technology were compared based on variables describing ownership of farm resources, and access to markets and information. Results show a higher fraction of sample households in Kenya kept improved dairy breeds, cultivated improved forages, used artificial insemination and veterinary services, and participated in dairy cooperatives than their counterparts in Ethiopia. The difference in the level of technology adoption between sample farmers in the two countries was attributed to the better market development for dairy products in Kenya than in Ethiopia. Farmers who adopted dairy technologies had more family labour, resided closer to markets and had better access to information compared to non-adopters. The results indicate that dairy technology adoption increases with increase in farm resource endowment and better access to markets.

Chapter 4 investigated the impact of adopting dairy technologies on household nutrition and income using propensity score matching and a sample treatment effect estimator. Results show that adopting crossbred dairy cows and improved forages increased household nutrition and income. The comparison of adoption impact estimates by propensity score matching and the sample treatment effect estimator indicated that unobservable variables have influence on technology adoption and impacts, which suggests that smallholders are heterogeneous in initial resource ownership conditions and in individual characteristics, such as entrepreneurial ability, motivation or ingenuity, attitude towards risk and networking ability. The variation in such initial resource ownership status and in individual characteristics may explain part of the variation in adoption of dairy technologies and their impacts.

Chapter 5 examined the influence of macroeconomic institutions and policies on adoption of technologies in the dairy sector. A functional-structural analysis framework was used to analyse the historical evolution of the macroeconomic institutions and policies, which are relevant to dairy development. Systemic failures, such as limited capacity of actors, absence of some key actors and poor interaction among actors, institutional problems and inadequate infrastructure, have been prevalent in Ethiopia during the period covered in this study (1960s -to date). Some of the important institutional problems were cumbersome bureaucratic processes, failures of accountability in public service delivery system, corruption, poor law enforcement, insecure property rights, rigid and restrictive procurement regulations, unclear and ever-changing government regulations, and protection measures that resulted in high import costs of technological inputs. Examples of infrastructural inadequacies include poor rural roads and unreliable supply of water and electricity. Out of the seven innovation functions studied, entrepreneurship, knowledge diffusion, market development and legitimacy creation have been particularly weak. In the analysis, the chapter illustrated how historical institutions and policies were important for technology adoption and dairy development.

In **Chapter 6** the findings of the empirical chapters are synthesised. The findings in the empirical chapters show that low adoption of the technologies that enhance the productivity of livestock production and water use efficiency stem from farmers' limited access to farm resources, differentials in potential welfare impacts of the technologies, lack of effective and reliable supply chains for inputs and outputs, inadequate physical infrastructure and weak institutions and policies. The findings show that smallholders have been subjected to multiple constraints. Given the multiple constraints at different scales and the associated transaction costs facing smallholders in rural Ethiopia, the returns to investment for the technologies may be too low to justify widespread adoption of the technologies. Therefore, smallholders are simply responding to the incentives and constraints of their agricultural circumstances. Unless the technologies are accompanied by simultaneous improvements in access to farm resources, input and output markets and measures to overcome institutional and policy barriers, large scale technology adoption in the near future appears unlikely. Therefore, adoption of technologies in the dairy sector requires interventions at production, storage, transportation, processing and marketing chains and at macroeconomic institutions and policies. In the short and medium term, dairy development programs in Ethiopia will have a better chance of success if they target farmers who have better resource endowments and who are connected to better-functioning value chains rather than blanket technology scaling-up strategies targeting the majority of smallholders. Future agricultural research needs to shift the focus from predominantly developing new biophysical technologies towards social science research that assesses issues at value chain, macroeconomic institutions and policies that influence adoption of technology.

Samenvatting

De vraag naar dierlijke producten, zoals melk, vlees en eieren groeit in Ethiopië als gevolg van bevolkingsgroei, stijgende inkomens en verstedelijking. Deze groeiende vraag naar melkproducten biedt kansen aan kleine boeren om beter in hun levensonderhoud te voorzien. Hoewel de toenemende vraag naar melkproducten alom erkent wordt in Ethiopië, is de zuivelsector nog niet bij machte geweest om voldoende melk te produceren om aan de vraag te voldoen, voornamelijk als gevolg van de lage productiviteit van de melkkoeien. Het landelijke gemiddelde van de melkgift van lokale melkkoeien is 1,9 liter per koe per dag en zelfs in de Ethiopische hooglanden, waar de huidige studie plaatsvond, is de gemiddelde melkgift slechts 2,3 liter per koe per dag.

Het gebruik van technologieën, zoals verbeterde koeienrassen en teelt van verbeterde voedergewassen wordt vaak als onontbeerlijk gezien om tot verbetering van de productie van het vee en van de efficiëntie van benutting van productiemiddelen te komen. De adoptie van dergelijke technologieën is echter altijd beperkt gebleven, ondanks veel inspanningen om deze wijd te verspreiden. Dit roept de vraag op waarom de meerderheid van de kleine boeren in de Ethiopische hooglanden deze zogenaamde melkveehouderijtechnologieën nooit geadopteerd heeft. De overkoepelende doelstelling van de huidige studie was dan ook om de factoren te begrijpen die van invloed zijn op adoptie van technologieën die de productie van melkvee en de efficiëntie van het watergebruik in de Ethiopische hooglanden verhogen. Deze studie wilde het begrip van de rol van dergelijke factoren uitdiepen op het niveau van de boerenfamilie, van de keten en van de macro-economische instituties en het beleid.

Hoofdstuk 2 behandelt de kenmerken van de bedrijfssystemen en de factoren die de waterproductiviteit van het vee (WPV) in gemengde gewas-vee-systemen beïnvloeden. We stelden de WPV vast voor verschillende gemengde gewas-vee-systemen en we onderzochten de effecten van demografische kenmerken van de huishouding en beschikbaarheid van bedrijfsmiddelen op de boerderij op de WPV.

De resultaten laten een behoorlijke variatie binnen en tussen bedrijfssystemen en tussen welvaartsklassen zien. Bedrijfssystemen verschilden wat betreft beschikbaarheid van arbeid en land, de waarde van de opbrengst van granen, de hoeveelheid regenwater die verdampte

in het proces van voerproductie en in de WPV. Over alles was de gemiddelde WPV in het studiegebied 0,21 US$ m^{-3}, waarbij de hoogste WPV van 0.34 US$ m^{-3} vastgesteld werd in het teff-millet bedrijfssysteem in het Fogera district en de laagste WPV van 0.13 US$ m^{-3} in het mais-sorghum bedrijfssysteem in Diga. De gemiddelde beschikbaarheid van familie-arbeid, het totale landbezit, het areaal onder voedselgewassen waarvan de gewasresten voor veevoer gebruikt konden worden en het areaal beschikbaar voor begrazing en de omvang van de veestapel en van de ossen waren alle hoger in huishoudens van hoge of midden welvaartscategorie dan in arme huishoudens. Regressieanalyse liet zien dat de leeftijd van het hoofd van de huishouding, de omvang van de veestapel en de beschikbaarheid van arbeid een positief effecten hadden op de WPV.

De belangrijkste doelstelling van **Hoofdstuk 3** is om te begrijpen waarom veel boeren in Ethiopië de technologieën gericht op verhoging van de melkproductie niet adopteerden. We vergeleken in deze studie Ethiopië met Kenia. Boeren die melkveehouderijtechnologieën adopteerden werden vergeleken met boeren die dit niet deden op basis van variabelen zoals eigendom van bedrijfsmiddelen en toegang tot markten en informatie. De resultaten gaven aan dat een grotere fractie van de huishoudens in Kenia verbeterde koeienrassen hield, verbeterde voedergewassen teelde, gebruikmaakte van kunstmatige inseminatie en veterinaire diensten en deelnam in zuivelcoöperaties dan van hun Ethiopische tegenhangers. Het verschil in de mate van adoptie van technologie tussen de boeren in de twee landen werd toegeschreven aan de hogere ontwikkeling van de markt voor zuivel in Kenia dan in Ethiopië. Boeren die melkveehouderijtechnologieën adopteerden hadden meer familiearbeid beschikbaar, woonden dichter bij de markt en hadden een betere toegang tot informatie dan boeren die niet adopteerden. De resultaten geven aan dat adoptie van melkveehouderijtechnologieën toeneemt met toenemend bezit van bedrijfsmiddelen en betere toegang tot markten.

Hoofdstuk 4 onderzoekt het effect van adoptie van melkveehouderijtechnologieën op de voedingsstatus en het inkomen van de huishouding met behulp van de zogenaamde “propensity score matching” en de “sample treatment effect estimator”. De resultaten laten zien dat adoptie van kruisingkoeien en verbeterde voedergewassen de voedingsstatus en het inkomen van de huishouding verbetert.

De vergelijking van schattingen van het effect van adoptie tussen de "propensity score matching" en de "sample treatment effect estimator" liet zien dan zogenaamde onzichtbare variabelen invloed hadden op de adoptie van technologie en op de effecten daarvan. Dit suggereert dat de kleine boeren niet alleen verschillen wat betreft bezit van bedrijfsmiddelen, maar ook in individuele eigenschappen, zoals ondernemerschap, motivatie of talent, durf en vermogen om te netwerken. Variatie in bezit van bedrijfsmiddelen en in individuele eigenschappen kunnen dus een deel van de variatie in adoptie van melkveehouderijtechnologieën verklaren.

Hoofdstuk 5 onderzoekt de invloed van macro-economische instituties en beleid op adoptie van technologieën in de melkveesector. Een analyseraamwerk waarin functie en structuur samen werden geanalyseerd werd gebruikt om de historische evolutie te evalueren van de macro-economische instituties en het beleid die van belang waren voor de melkveehouderijontwikkeling.

Systemische fouten, zoals beperkte capaciteit van de actoren, afwezigheid van sommige sleutelactoren en een slechte interactie tussen actoren, institutionele problemen en onvoldoende infrastructuur waren aanwezig in Ethiopië gedurende de periode die onderzocht werd in deze studie (1960-heden). Enkele van de belangrijkste institutionele problemen waren logge bureaucratische processen, onduidelijkheid over verantwoordelijkheden in het systeem van openbare dienstverlening, corruptie, slechte wetshandhaving, onzekere eigendomsrechten, rigide en beperkende regels voor aanschaf, onduidelijk en almaar veranderende overheidsregels en beschermende maatregelen, die resulteerden in hoge kosten van import van melkveehouderijtechnologieën. Voorbeelden van infrastructurele tekortkomingen waren slechte landwegen en onbetrouwbare voorzieningen van water en elektriciteit. Van de zeven innovatiefuncties die bestudeerd zijn, waren vooral die van ondernemerschap, kennisverspreiding, marktontwikkeling en het scheppen van legitimiteit in het bijzonder zwak. De analyse in dit hoofdstuk illustreert hoe historische instituties en beleid belangrijk waren voor technologieadoptie en melkveehouderijontwikkeling.

In **Hoofdstuk 6** worden de bevindingen van de empirische hoofdstukken samengevoegd. Deze bevindingen van de empirische hoofdstukken laten zien dat de lage adoptie van technologieën die de productiviteit van melkvee verhogen en de efficiëntie van het watergebruik verbeteren hun oorsprong vinden in de beperkte beschikbaarheid van bedrijfsmiddelen, verschillen in de mogelijke effecten op welvaart van de technologieën, gebrek aan effectieve en betrouwbare ketens voor inkoop en afzet, onvoldoende fysieke infrastructuur en zwakke instituties en beleid. De resultaten laten zien dat de kleine boeren onderworpen zijn aan een veelvoud aan beperkingen. Dit veelvoud aan beperkingen op verschillende schaalniveaus en de daarmee samenhangende kosten voor kleine boeren in Ethiopië, zouden er toe kunnen leiden dat de opbrengsten op de investeringen voor de technologieën te laag zijn om een brede adoptie te bewerkstelligen. Om die reden doen kleine boeren niets anders dan reageren op de prikkels en beperkingen van hun landbouwkundige omgeving. Alleen als de introductie van technologieën vergezeld gaat van gelijktijdige verbeteringen van de beschikbaarheid van bedrijfsmiddelen, van inkoop- en afzetmarkten en van maatregelen om institutionele en beleidsmatige barrières te slechten zal grootschalige adoptie in de nabije toekomst mogelijk lijken.

Om die reden vergt adoptie van melkveehouderijtechnologieën interventies op gebied van productie, opslag, transport, verwerking en marktketens en macro-economische instituties en beleid. Op de korte en middellange termijn zullen melkveehouderijontwikkelingsprogramma's in Ethiopië een grotere kans van succes hebben als ze gericht zijn op boeren die meer bezit hebben en die al deel uitmaken van functionerende ketens dan wanneer het open strategieën zijn gericht op opschaling van technologiegebruik bij de meerderheid van de kleine boeren. Toekomstig landbouwkundig onderzoek moet haar blik verplaatsen van het voornamelijk ontwikkelen van nieuwe biofysische technologieën naar sociaal wetenschappelijk onderzoek dat de zaken in kaart brengt die invloed hebben op de adoptie van melkveehouderijtechnologieën op niveau van de keten, de macro-economische instituties en het beleid.

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About the author

Kebebe Ergano Gunte was born on 7 September, 1975 at Hossana, Ethiopia. He obtained his BSc in Agriculture in 1995 from Addis Ababa University and his MSc in Agricultural Economics in 2000 from Harayana University, India. He was awarded a PhD-fellowship from Wageningen University in 2011 and he started his sandwich PhD in the same year at the Animal Production Systems group of Wageningen University. He conducted part of his PhD research while he worked as research officer at the International Livestock Research Institute (ILRI) based in Ethiopia. Before he commenced the work at ILRI in 2008, he was lecturer at Hawassa University (2000-2008) and district level extension worker (1996-1998). He acquired skills in quantitative and qualitative research methods in conducting complex surveys, in data management and analysis using econometric tools. His research interests cover modelling farmers' agricultural technology adoption, impact evaluation and political economy analysis. He is married and has got a son.

List of publications

Journal articles

1. **Kebebe E.G.,** A.J. Duncan, C. Gardebroek, I.J.M. de Boer, S.J. Oosting 2015. Impact of dairy technology adoption on household nutrition and income in Ethiopia (Finalising for submission to Food Security)

2. **Kebebe E.,G**. A.J. Duncan, L. ,Klerkx, I.J.M. de Boer, S.J. Oosting 2015. Understanding socio-economic and policy constraints to dairy development in Ethiopia through innovation systems function analysis (Submitted to Agricultural Systems and positively peer-reviewed)

3. **Kebebe E. G.**, S.J. Oosting, A.J. Duncan, I.J.M. de Boer 2014. Characterisation of adopters and non-adopters of dairy technologies in Ethiopia and Kenya (Submitted to Wageningen Journal of Life Sciences)

4. **Kebebe, E.G.**, S.J. Oosting, Haileslassie, A.J. Duncan, I.J.M. de Boer, 2014. Strategies for improving water use efficiency of livestock production in rain-fed systems. *animal*, 1-9.

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1. **Kebebe Ergano**, 2013. Innovation platforms enabling innovations in livestock sector in Ethiopia. In Renewing innovation systems in agriculture and food, eds. E. Coudel, H. Devautour, C.T. Soulard, G. Faure and B. Hubert. *Wageningen Academic Publishers*. 217-218.

Selected papers presented in conferences

1. **Ergano, K.**, Duncan, A.J., Oosting, S.J. 2013. Unlocking the potential of livestock technologies in Ethiopia: Shifting from individual pieces to optimizing the sum of the parts (presented at the Nile Basin Development Challenge (NBDC) Science Workshop, 9-10 July, 2013, Addis Ababa, Ethiopia).

2. Haileslassie, A., Descheemaeker, K., Blummel, M., Craufurd, P., **Ergano, K.** 2013. Entry Points to Improve Livestock Water Productivity in Selected Forage Based Livestock Systems. In: Proceedings of the 22nd International Grasslands Conference, 15-19 September, 2013, Sydney, Australia. p. 1830 - 1832.

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Education certificate

Completed training and supervision plan[1]
The basic package (3.0 ECTS) • WIAS Introduction Course (18 - 21 Apr. 2011) • Course on philosophy of science and/or ethics (30 Mar.-1 Apr. 2011) • Introduction interview with WIAS scientific director and secretary(10 Mar. 2011) • Introduction interview with WIAS education coordinator (14 Jan. 2011) • Introduction interview with WIAS PhD students confidant (10 Mar. 2011)
International conferences (5.7 ECTS) • 9th International Conference on the Ethiopian Economy, Addis Ababa, Ethiopia (21–23 Jul., 2011) • TechFit Workshop to Develop a Tool for Feed Technology Screening and Prioritization, organised by ILRI in Deradun, India (19-22 Sep., 2011) • Increasing Agricultural Productivity and Enhancing Food Security in Africa. Addis Ababa, Ethiopia (1-3 Nov., 2011) • Third International Forum on Water and Food (IFWF3), Tshwane, South Africa organised by CGIAR Challenge Program on Water and Food (CPWF) (14-17 Nov., 2011) • N2 AFRICA Workshop, Addis Ababa organised by PPS Group, WUR (30 Apr-2 May 2012) • NBDC Science workshop (9-10 Jul., 2013)
Presentations (4.0 ETCS) • Adoption of interrelated dairy technologies in crop-livestock mixed farming systems: Evidence from Blue Nile Basin of Ethiopia. WaCASA meeting, WUR oral presentation (8 Apr., 2013) • Unlocking the potential of livestock technologies in Ethiopia: Shifting from individual pieces to optimizing the sum of the parts. NBDC science Workshop, ILRI, Addis Ababa, Oral presentation (9-10 Jul., 2013) • Business Models for Commercialization of Dairy Farming in Ethiopia. Livestock Market Development Project, Debre Zeit, Ethiopia (25 Jul.-8 Aug., 2013) • Strategies for improving water use efficiency in livestock feed production in rain-fed systems, Oral presentation (13 Feb., 2014)
In-Depth Studies (41.5 ETCS) • Rapid Market Appraisal in Livestock and Fodder Markets organised by International Livestock Research Institute (4-8 Nov., 2008) • Orientation on Mathematical Modelling in Biology (28 Feb.-4 Mar., 2011) • Introduction Geo-Information Science (GRS-10306) (2011) • Advanced Agricultural Business Economics (BEC-30306) (2011) • Innovation Management and cross-disciplinary design (COM 21306) (2011) • Econometrics (AEP-21306) (2011) • Advanced Econometrics (AEP-60306) (2011) • Institutional Economics and Economic Organisation Theory (AEP-20806) (2013) • Animal breeding and sustainable food security (28 Oct. – 1 Nov., 2013)
Professional skills support courses (3.2 ETCS) • Experimental and Survey Design, Data Management, Data Analysis and Presentation organized by International Livestock Research Institute (20-25 Jul., 2008) • Techniques for Scientific Writing and Presentation(5-8 Jun. 2011) • Mobilising your scientific network (MSN) (19 and 27 Mar. 2014)
Research skills training (6.0 ETCS) • Preparation own PhD research proposal (2011)
Didactic skills training (1.5 ETCS) • Supervision of one MSc thesis (2011-2012)

[1] With the activities listed the PhD candidate has complied with the educational requirements set by the Graduate School of Wageningen Institute of Animal Sciences (WIAS). One ECTS equals a study load of 28 hours.

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