ACCESS TO MOBILE PHONE TECHNOLOGY AND ITS EFFECTS ON LIVESTOCK MARKETS LINKAGES IN THE PASTORAL DRYLANDS OF KENYA

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DOCTOR OF PHILOSOPHY

(Agricultural and Applied Economics)

JOMO KENYATTA UNIVERSITY

OF

AGRICULTURE AND TECHNOLOGY

2024

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Agricultural and Applied Economics of the Jomo Kenyatta University of Agriculture and Technology

2024

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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DEDICATION

I dedicate this work to my parents, Mr. Julius Chelang'a and Mrs. Elizabeth Yator. I thank them for the love of life and for managing me through formal and informal education.

ACKNOWLEDGMENT

I wholeheartedly appreciate Prof. K. Muendo of JKUAT and Dr. N. Jensen of the International Livestock Research Institute (ILRI) for their great supervisory and mentorship role during the study. They taught me the interface between science and life. It was efficient and sustainable. In the same vein, I also thank my former work supervisors at ILRI, Dr. Andrew Mude and Prof Munenobu Ikegami. They believed in me and gave me the chance to advance my research and academic career against all odds.

I also thank ILRI and the German Academic Exchange Services, Deutscher Akademischer Austausch Dienst (DAAD) for their collaboration in providing financial support for this research work. I appreciate JKUAT for the institutional support. The profound coordination at Department of Agricultural and Resource Economics at JKUAT and the capacity development unit at ILRI is much applauded.

I also acknowledge my colleagues at ILRI for their support and motivation during the study. While the experience with the IBLI team was heart touching, the brown bags at with fellows and the seminar series at JKUAT were effective.

I also appreciate the pastoralists of northern Kenya for allowing the team of excellent contributors, enumerators, and supervisors to conduct the time and mind-thrilling recurrent data collection. It was a great learning experience.

I also thank Prof. G. A. Obare and Prof B. K. Njehia for providing me with a solid research foundation and support during my MSc. It worked and still works. Dr. Geoffrey Ochieng' Otieno gave me confidence and support to settle at JKUAT--Thank you 'Chemuos'. I also appreciate Leonard Kirui for his constant reminders and assurance through the different stages of this work.

My wife Catherine Korir took care of the family and I salute her. I am indebted. I also give special appreciation to my children TonnyBrian, Jeptoo, Jerop, Jelimo, Morgan, and Jebichii for keeping up with a boring and absent father. You are the best children.

Above all, God loves us. I would dare say, “Nothing confounds when God is the main source of variation”.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACRONYMS AND ABBREVIATIONS

ADF	Augmented Dickey-Fuller
ADF	Augmented Dickey-Fuller
ANOVA	Analysis of Variance
ATE	Average Treatment Effects
CRDW	Cointegrating Regression Durbin–Watson
CV	Coefficient of Variation
DHM	Double Hurdle model
DID	Difference-in-Difference
ECM	Error Correlation Model
ERM	Extended Regression Model
ESTJ	Enke-Samuelson-Takayama-Judge
FAO	Food Agricultural Organization
FE	Panel Fixed Effects
GDP	Gross Domestic Product
GMO	Genetically Modified Food
Gok	Government of Kenya
GPS	Global Positioning System
ICT	Information Communication Technology

ILRI International Livestock Research Institute

IMR Inverse Mills Ratio

KAMIS Kenya Agricultural Market information System

KBC Kenya Broadcasting Corporation

KBS Kenya Bureau of Standards

KLMC Kenya Livestock Marketing Council

KPSS Kwiatkowski-Philips-Schmidt-Shin

LINKS Livestock Information Network and Knowledge Systems

LOP Law of One Price

LR Large Ruminants

MIS Market Information Systems

MLD Ministry of Livestock

MoLF Ministry of Livestock and Fisheries

MSM Markov switching model

M-Turk Mechanical Turk

ODA Overseas Development Authority

ODK Open Data Kit

OLS Ordinary Least Square

PBM Parity Bound Model

PLS	Partial Least Squares
PP	Phillips-Perron
PTC	Proportional Transaction Costs
RCT	Randomized Control Trial
ROT	Rank Order Tournament
SAPs	Structural Adjustment Programs
SEM	Structural Equation Modeling
SR	Small Ruminants
TAR	Threshold Autoregressive
TVECM	Threshold Vector Error Correction Models
UNDP	United Nations Development Program
USAID	United States Agency for International Development
VAR	Vector Auto-Regression
VECM	Vector Error Correlation Model
VHF	Very High Frequency

ABSTRACT

Market information plays an important role in the functioning of markets. The recurrence of market information asymmetry and associated market failure has been a challenge in developing nations. Many scholars argue that the current age of improved information and communication technologies, especially the ubiquity of mobile phones, would reduce the information asymmetry gap. Therefore, this study focused on evaluating whether mobile phones have impacted livestock marketing in the pastoral drylands of Kenya a context traditionally characterized by high information asymmetry. The first specific objective investigated market integration for 6 purposively selected livestock markets for 43 weeks (2019-2020) using weekly livestock market prices to get insights on the regional scale. The Vector Error Correction Model framework was used to estimate the short and long-run market price causal relationships. The results indicate that a higher proportion of price variation in larger markets in the region was due to its shocks while variation in smaller markets originated from the larger markets. Price transmission was also evident between markets operating in different trading routes. However, markets located close to production catchments exhibited lower price trends despite being connected. These results suggest a strong influence of the recent infrastructural investments on price transmission between markets in the region. The second specific objective used 11 years panel (2009-2020) data of 924 households to evaluate the impact of mobile-phone access duration on market participation dynamics. It leverages the expansive geography of the study area and the temporal heterogeneity across space in setting up network towers by telecommunication companies, to instrument the duration of access to mobile phones among different subsamples at sublocation levels. A panel-data Ordered Tobit model that accounts for sequential decision-making on the discrete and continuous market participation outcomes was used for analysis. The findings show variation in impact of increased duration contingent on distance to the main market in the region. The results encourage tailored investments that increase the competitiveness of markets near production catchments and those that support the building of herds. The third specific objective examined whether access to information created by processing the submitted data could be used as a no-cost incentive to increase participation in crowdsourcing for livestock market information. To do so, a randomized provision of information on average prices from surrounding livestock markets to contributors of a micro-tasking platform called KAZNET was conducted for nineteen weeks. The main value offered by the treatment was that contributors could easily track livestock market prices from the main markets in the region. A difference-in-difference identification strategy was used to estimate the treatment effects. The treatment increased participation in livestock marketing tasks as well as in other tasks that were unrelated to the information treatment. The findings show that a crowdsourcing model that generates information that is valuable to its contributors and can be used to improve participation and increase the value of the data generated. These results also show that micro-tasking coupled with providing access to timely information could improve the sustainability of data collection and dissemination efforts in rural settings.

CHAPTER ONE

INTRODUCTION

1.1 Agricultural Market Information Linkages

Market information concerns producers, consumers, value chain players, governments, and other stakeholders in a wide range of contexts and nations. In a bid to address the concerns, market stakeholders have over time developed evolving Market Information Systems (MIS). The systems have operated across the world for centuries, providing information that has enabled the stakeholders to overcome knowledge deficits and make informed marketing decisions. Anecdotes indicate that the Pharaohs of Egypt and other ancient monarchies in China and Rome used MIS to manage public grain stocks and prices to dampen the impacts of famines. Over time, the value of information in facilitating market functioning has been a growing concern of economic theory (Akerlof, 1970). It has gradually advanced in scope and stakeholders involved, exclusively to improve market efficiency, reduce market frictions, enhance equity and influence public policy (Nakasone *et al.,* 2014).

In the last decade, information sharing, and the exchange of goods and services have been largely driven by digital technologies. A report by World Bank (2016) shows that digital technologies have widely spread across the world enabling growth, expanding opportunities, and improving service delivery in many instances. However, “Digital dividends”, defined as the broader benefits of using technology, have not only lagged behind but are also unevenly distributed in some parts of the world. Out of an estimated 6.85 billion people living within mobile coverage, 5.2 billion have mobile phones and 3.5 billion have internet access as of the end of the year 2018 (GSMA, 2018).

Despite the promising coverage, only 40% of the population in low-income countries is connected, compared to 75% of the population in high-income countries (GSMA, 2019). The population outside coverage, not having mobile phones and limited internet users largely depend on agriculture (Deichmann *et al.,* 2016a). However, there is evidence of increased agricultural productivity and market linkages attributed to the adoption of digital technologies in production and marketing in low and medium-income countries (Wani *et al.*, 2016). This points to a huge potential and a growing link between information technologies and agricultural development outcomes mainly through mobile-phone-based MIS in developing nations in Asia and Africa.

In Africa, the proliferation of liberal policies through the structural adjustment programs in the 1980s' was a major driving force to embrace MIS. Governments expected to use MIS to continue monitoring major product lines and regions after relaxing direct control of markets (FAO, 1997). Dissemination of basic data collected, mainly on targeted products was done through mainstream media like radio, bulletins, and posters (Reynders, 2012). In most market environments, average prices were the major target, but the advent of mobile and internet technology enabled wider scope of target data, improved speed, better quality, precise forecasting, and lower collection and dissemination costs (Galtier *et al.*, 2014). These advancements have mainly been observed in urban and peri-urban settings where aggregate connectivity of market and communication technologies have existed for a longer period. However, in areas further away from the major cities where agriculture is the main source of livelihood, communities are surrounded by less competitive markets and remain rather poorly connected.

1.2 Livestock Market Linkages in Kenya

There is a high correlation between the growth of Kenya's economy to the growth of agricultural sectors (Figure 1.1). It follows that interventions targeting the improvement of the livestock sub-sector, have a strong impact on reducing poverty and hunger (Barrett & Luseno, 2004). Livestock is mainly produced in the drylands of Kenya, which constitute 84 percent of the landmass, and are home to 10 million people. The subsector also contributes to 10% of the country's Gross Domestic Product (GDP) and 50 percent of agriculture's GDP (KNBS, 2023). Many communities in the drylands rely on livestock for their livelihood as a source of income, food, and stock. Drylands are the main origin and surplus regions for livestock products, feeding the major cities and other deficit regions across the year.

The local demand exceeds supply, and the deficit needs is generally satisfied from neighboring countries like Ethiopia, Tanzania, and Somalia (KNBS, 2023).

A report by the Kenya National Bureau of Statistics (KNBS) economic survey (2019) showed a 7.4 percent increase in cattle and calves slaughtered from 2017 to 2018. With the increasing human population, mostly in cities, innovations that would increase supply from major production zones are needed to meet the increasing demand for livestock products (GOK, 2018). In 2018, for instance, the annual per capita consumption of bovine meat and milk consumed increased by 11.1percent and 4.4 percent to 14.0 kilograms and 93.3 kilograms, respectively (KNBS, 2019).

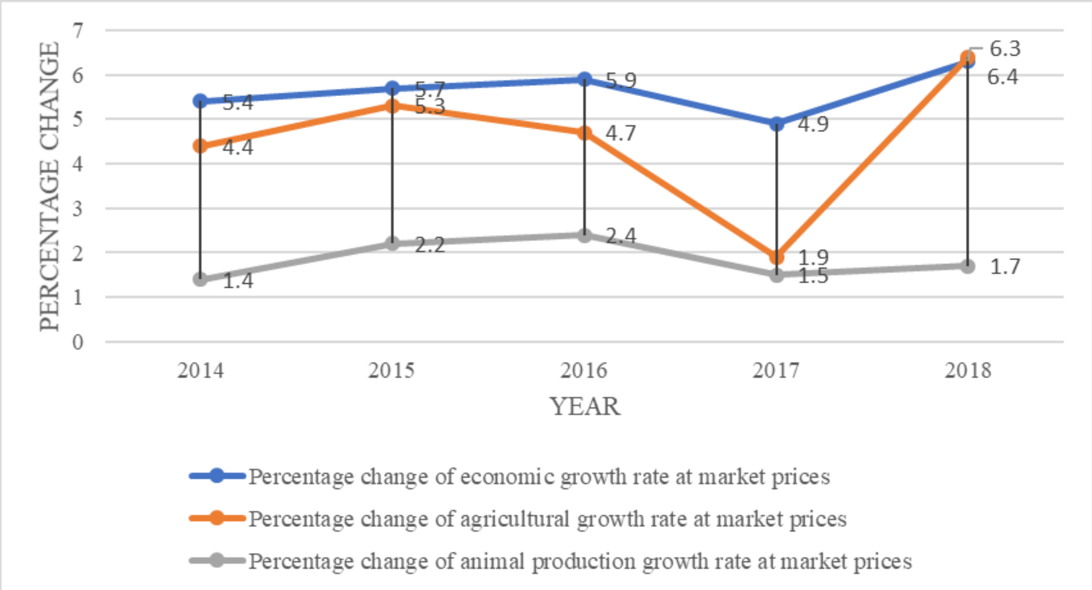


Figure 1.1: Percentage Change in the Economic Growth Rate per Year in Kenya

Source: Kenya Economic Survey 2019

Notwithstanding the demand and supply imbalance, pastoralists face several production and marketing challenges that inhibit the growth of the livestock subsector and the improvement of their livelihoods. Drought is the most common risk faced due to rainfall that is not only low but also erratic (Opiyo *et al.*, 2015). This increases the cost of production through extended migration, purchase of inputs, and frequent animal loss. The vulnerability of pastoralists to drought is worsened by the poor functioning of markets and thus limiting optimal gains from a marketed surplus (Upton *et al.,* 2016). Furthermore, poor roads, information asymmetry, and remoteness of pastoral lands contribute to high transaction costs and poor market access which further limit their bargaining power for fair prices (Shiferaw *et al.,* 2011). Slow financialization of these risks by private and public sectors further worsens the situation. Nonetheless, several efforts including those targeting improvement of livestock market linkages through MIS have evolved to ameliorate the situation.

1.3 Evolution of MIS in the Drylands of Kenya

Over the past four decades there have been several efforts by public and private entities to improve the poor state of rural agricultural market linkages in Kenya. United Nations Development Program (UNDP) began the first digital MIS in 1978 targeting smallholder information on crops mainly from markets in major crop-growing zones. In 1992, MIS focusing on Kenyan livestock began through a collaboration between the Overseas Development Authority (ODA) and the Ministry of Livestock Development (MLD) (Stuth *et al.,* 2006). Market information was collected by locally recruited monitors, and in limited cases by government extension workers. Data was then sent via Very High Frequency (VHF) radio, fax, telephone, and spot delivery to a central location, usually Nairobi City, for analysis. It was then disseminated through Kenya Broadcasting Corporation (KBC) radio, newspapers, telephone, and notice boards mounted at entrances of some markets.

Livestock markets were comprehensively connected with MIS from 2003 through a United States Agency for International Development (USAID) project named Livestock Information Network and Knowledge Systems (LINKS). The main objective of the project was to collect and disseminate reliable livestock market information that would revitalize the livestock subsector (Stuth *et al.,* 2006). Before 2003, small and short-period MIS rolled out by development agencies in collaboration with the Kenyan government had all collapsed. To ameliorate the situation, the Kenya Livestock Marketing Council (KLMC) was formed in 2003 as a user association faction affiliated with the Ministry of Livestock and Fisheries

(MoLF) to support LINKS. The system has since undergone an evolution, sometimes failing to report market prices, but it is still running to date. The most recent effort that largely builds on the LINKS infrastructure, is the Kenya Agricultural Market information System (KAMIS).

Currently, 82% of Kenyan people have access to mobile phones, and 19% use smartphones (GSMA, 2018). While network access is most reliable in urban and peri-urban areas, network coverage continues to expand into rural and remote areas, providing the prospect of collecting and disseminating information via mobile phones even to communities living on drylands (Gesare *et al.,* 2017). Although internet-enabled MIS leads to an increased number of stakeholders reached, the gains are characterized by recurrent costs that are often difficult to attach to users or for users to pay sustainably (Shepherd, 2016). Even though the advent of mobile phone use relaxed some earlier constraints, the potential of MIS has not been fully attained in many contexts (Jensen, 2007; Deichmann *et al.,* 2016). This implies that research and development practitioners are yet to craft sustainability strategies that would inform policies that further lessen the digital divide. Despite the challenges, there is evidence of a few stakeholders using the information generated through established MIS (Bailey *et al.*, 2001; Roba *et al.*, 2017).

In the past 10 years, major roads connecting livestock trading routes have been under construction, with the Moyale-Marsabit-Isiolo-Nairobi tarmac route having been completed in 2017. Major feeder roads have also been re-carpeted and maintained better than ever before, hence allowing easier access to markets. The communication infrastructure has not only been setup but also upgraded progressively from 2G, 3G and 4G across different geographical clusters. Similarly, the modernization of old livestock markets and the construction of others in areas closer to pastoralists have also been on the rise. Currently, major intermediate markets and a few feeder markets have improved facilities that allow a better trading environment and management. Furthermore, policies that boost the management of these markets through a mix of locally constituted officials and government officers have also contributed to the growth (Njiru *et al.,* 2017). Although many areas remain inaccessible, the infrastructure investments already made represent a huge milestone in the process of opening the drylands. The investments further present a recipe for a paradigm shift in the lens of assessing dryland markets that include testing the applicability of innovative digital engagement common in urban and peri-urban settings.

1.4 Crowdsourcing Potential and Application

The term crowdsourcing was coined by journalist, Howe in 2006 in wired magazine to describe the act of outsourcing by an organization to an undefined group of people outside the organization without specific expertise through an open call. The popularity of the word is attributed to the existence and widespread use of the internet. Others argued that it existed even before Howe's article definition. A commonly used example is work by n society he called it "wisdom of crowds" in his book. In subsequent years, “Crowdsourcing” and “Wisdom of Crowds” have been used interchangeably, spurring Surowiecki (2004) who argued that crowds were wiser than the smartest individuals i many other definitions by scholars and industry players that adapted the process to their areas of specialization. Estellés-Arolas & González-Ladrón-De-Guevara (2012) conducted a comprehensive review of articles from 2006 to 2011 on crowdsourcing and crafted a definition deemed to reconcile most semantic confusions in academic publications.

To further pursue the sustainability challenge of MIS, this study explores the use of mobile phones and the internet to outsource information gathering through crowdsourcing. Crowdsourcing initiatives have grown exponentially in the past 10 years as an alternative to entities' problem-solving tools. Research done by Jensen *et al.* (2017) on crowdsourcing for pastoral rangeland conditions, provides a foundation for further investigations on the application of crowdsourcing in the dryland markets environment.

There are popular crowdsourcing platforms used in solving critical business, technical, and scientific research problems across the world today. These include Amazon Mechanical Turk (M-Turk) for data cleaning, entry, and content creation; Designhill, for logo designs; RedesignMe, for product design; InnoCentive, for content creation and micro-tasks, among many others (Darwin, 2019). In agricultural sciences, crowdsourcing has been applied in many notable spheres such as soil data, weather data, phenology and crop calendar, weeds, pests and diseases, yield, and vegetation status (Rossiter *et al.,* 2015). These platforms are known for providing innovative solutions, improving data quality, reducing cost, and providing high-resolution data to users (Kietzmann, 2016). More improvements in the quality of data collected are observed when the capabilities of the crowd are identified, motivated, and utilized (Saxton *et al.,* 2013).

Despite the overarching benefits and extensive use in many fields, there are mixed views on the strengths of micro-tasking (Liu, 2017; Phuttharak & Loke, 2018). Critics argue that the data generated through micro-tasking have high variability or are biased when compared to data collected by scientists, technicians, or enumerators, using conventional instruments. However, proponents of micro-tasking argue that projects using non-expert contributors continue to produce high-quality data, equivalent to and sometimes surpassing trained enumerators (Eklund *et al*., 2019). Neutral scholars and practitioners argue that each dataset generated through micro-tasking should be judged individually, based on the context in which the project is implemented as it could strongly complement traditional methods (Uhlmann *et al*., 2019).

In general, to achieve economic development, the World Bank report (2016) and the GOK Vision 2030 (2010) emphasize the need to expand the inclusion of systematically marginalized communities into equal market environments. The inclusion is even more important in regions where a greater proportion of the population depends on one main product, like in drylands where livestock is the main productive asset. In these regions, better-functioning markets would benefit both the pastoralists and stakeholders along the livestock value chain. At the household level, pastoralists would gain more by participating in competitive markets. At the macro-level, the existence of competitive markets is known to foster market integration, a situation where the transmission of price signals and the flow of products are effective. While other factors are necessary for market competitiveness to prevail, access to accurate and timely market information by market stakeholders is paramount.

1.5 Statement of the Problem

Over several decades, the information scarcity problem has adversely dampened the growth of competitive pastoral livestock markets. The persistence of the information scarcity problem is attributed to poor public and private investment in infrastructure leaving the vast pastoral lands systematically remote and difficult to access. For instance, pastoral communities are lagging in the adoption of known transformative technologies like mobile phones due to poor network connectivity and a lack of complementary services that support the gainful use of the technologies. In the recent past, the dawn of increased investment by government, private and development agencies in better physical infrastructure and mobile network connectivity offers the potential for reduced information scarcity and better-functioning markets. However, to date the impact of these changes on market integration, pastoralists' market participation behavior, and the potential of further engaging pastoralists using digital technologies, remain unclear.

The purpose of this study therefore was to investigate whether there are significant observable changes in the pastoral livestock market linkages in terms of market integration and pastoralists' market participation attributed to mobile phone access and usage. The study also explored the potential for engaging the dryland market stakeholders in crowdsourcing livestock market information as an effort to further reduce the information scarcity gap. These aspects are important for three reasons: i) the livestock sub-sector is increasingly becoming important to the dryland populations, national economy, and beyond; ii) the recent improvement in infrastructure e.g. road and mobile phone access, provides an avenue to describe pastoral markets in new ways that should attract more public and private investments; iii) the literature on the role of information technology in transforming agricultural development has been focused on crops, especially the major staples, leaving the livestock subsector, especially pastoral production system poorly addressed.

1.6 Objectives of the Study

This research bridges the existing gap of the role and potential of mobile phone-based information technology in reducing information scarcity and transforming agriculture in pastoral production systems. The precise inquiry examined the following specific objectives:

i. To determine the current level of integration in dryland livestock markets of Kenya.
ii. To determine the impact of duration of access to mobile phones on market participation behaviors of pastoralists in the drylands of Kenya.
iii. To determine the impact of market price information feedback as a complementary incentive on the participation of pastoralists in crowdsourcing in the drylands of Kenya.

1.7 Research Hypotheses

The following hypotheses were tested:

i. Livestock markets in the drylands of Kenya are not significantly integrated.
ii. The variation in the duration of access to mobile phones does not significantly influence the market participation of pastoralists in the drylands of Kenya.
iii. The provision of market price information feedback as a complementary incentive does not significantly increase the participation of pastoralists in crowdsourcing in the drylands of Kenya.

1.8 Justification of the Study

In a wider spectrum, the study focuses on illuminating possible pathways of improving the livelihoods of pastoral communities through increased access to market information. This is primarily important because livestock production remains the main livelihood activity among pastoralists and a major contributor to the national economy. Conversely, pastoralists not only face frequent covariate environmental risks like droughts and diseases but also continue to suffer unwarranted market risks that should have been minimised in the current age of advanced digital technology as observed in other production systems locally and internationally.

Essentially, efficient and functioning markets could offer pastoralists opportunities to benefit from the sale of livestock when prices are favorable, purchase necessities to support their households, reduce herd loss during droughts, and use the surplus income to make more informed production and marketing endeavors (Little *et al.*, 2014). In this regard, investments targeting a reduction in information scarcity are required to transform markets and reduce the risks faced. However, different interventions attempting to fill the information gap over the past have been limited because livestock markets are dynamic and complex.

Several studies have highlighted the importance of market information (Jensen 2007; Wyche & Steinfield, 2016), while others highlighted failures attributed to limited market information (Roba *et al*., 2017). Policy recommendations to address the effectiveness of markets have mostly been on the improvement of infrastructure and "getting prices right" (von Cramon-Taubadel, 2017). The findings from these studies justify more inquiry, especially on how mobile phone-based information technologies affect the information asymmetry gap in the changing rural agricultural landscape. To further this inquiry, this study focused on the three related concepts: at the market level, through the study of pastoral livestock market integration; at the household level, through the study of household market participation; and at individual pastoralists' level, through the study of incentives necessary to sustain participation in information gathering through micro-tasking-based crowdsourcing.

1.9 Organization of the Study

This research thesis is organized into seven chapters. Chapter one provides a background of market information systems from the global to the local context. It continues to motivate the problem by providing a condensed view of crowdsourcing and how it fits into the context of livestock market information. This is followed by a statement of the research problem, objectives, and hypotheses. The chapter ends by providing a brief description of the significance and contribution of the study.

Chapter two follows with a detailed literature review of the relevant work done previously and the research gaps. It begins with expounding the pastoral regional state of market integration, followed by household-level market participation, and finally on crowdsourcing, detailing both the rationale for setting it up and incentivising its application.

In each concept, the justification of its inquiry and how it relates to mobile phone-based information technology is described. Prior studies related to each concept and intervention in related contexts across the world are also synthesized. A summary of the key issues in the studies reviewed and the research gap for each concept is finally detailed. Chapter three covers the theoretical foundation, econometric specifications, and estimation procedures deemed suitable for each objective. The chapter also details the data collection methods, data types, and experimental designs.

Chapter four describes the state of market integration in pastoral markets using crowdsourced data. It provides details of market price trends, cointegration, as well as short and long-run markets causal relationships. Chapter five begins with a description of pastoralists' mobile phone access and its effect on their households' market participation behavior. This is followed by a disaggregated analysis and discussion of small and large ruminants' market participation. It further provides a detailed analysis of mobile phone access on the discrete and continuous components of market participation.

Chapter six describes the platform used to crowdsource the dryland information. This includes details of the flexibility of the platform to track various indicators. It further describes the incentives used to motivate pastoral communities to crowdsource using the platform. The chapter shows the different levels of participation in crowdsourcing caused by different incentive regimes tested. Chapter seven provides the summary of the study results, conclusions, recommendations, limitations, and areas for further research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter gives a conceptual and empirical account of key concepts studied in the three objectives outlined in chapter one. It focuses on the link between access to mobile phones and changes observed in spatial market integration, market participation, and crowdsourcing. From the review, the research gaps are identified and justified in the context of existing literature.

2.2 An Overview of Market Integration

The study of market integration originates from difficulties experienced by scholars in empirically defining a “market”. Traditionally, markets are known to be places where people meet to exchange goods and services. In contemporary economics, the definition of the market has evolved into a platform that facilitates the exchange of goods and services. In both cases, the challenge of precisely defining a market using empirical strategies still prevails (Barrett, 2005). Attempts to use spatial equilibrium models in the 1950s faced many criticisms mainly due to market failures observed over the period (Fackler & Goodwin, 2001; Barrett & Li, 2002). However, the belief in the role of the market in the efficient allocation of goods and services continued (Bressler & King, 1978). Some scholars e.g., Barrett (2001) queried the effectiveness of markets in fulfilling their presumed role. Notwithstanding the puzzles, several scholars resorted to studying the concept of market integration in a bid to overcome the empirical constraints in understanding both international and regional markets (von Cramon-Taubadel, 2017).

Stigler (1961) defined market integration as a manifestation and measure of ignorance of buyers and sellers. In a different terminology, Barrett (1996) defined integration as the transfer of Walrasian excess demand from one market to another. Many other definitions of market integration exist (Fackler & Goodwin, 2001; Negassa *et al.*, 2003; Amikuzuno, 2009). Spatially separated markets are deemed to be more integrated if price signals of tradable commodities are transmitted effectively. The notion of price transmissions and tradability of a commodity between spatially separated markets underpins the study of market integration (Fackler & Tastan, 2008; Rapsomanikis *et al*., 2006).

Market integration is an important indicator of economic development, and studies on this topic have evolved over the last five decades in a bid to explain weaknesses in economic theory on addressing market failure. In Africa, studies focusing on major policy shifts like the 1980s' Structural Adjustment Programs (SAPs), liberalization policies in the 1990s' among countries', and/or regional-specific policies are common (Alderman, 1992; Rashid, 2004). Lately, global trends like economic depression have shaped a new crop of studies focusing both on global and regional contexts of market integration like the 2007/2008 economic crisis (Acharya *et al.*, 2012; Akhter, 2017). Other dimensions of market integration studies delved into the responsiveness of markets to changes in information access conditions (Katengeza *et al.,* 2011), improvement in physical infrastructure connecting the markets (Escobal & Arturo, 2005), and environmental shocks like prolonged droughts (Salazar *et al.,* 2018). Studies on market integration continue to be insightful as markets evolve and new methods of evaluation are formulated (von Cramon-Taubadel, 2017).

2.2.1 Conceptual Framework for Agricultural Market Integration

Several concepts are used in the study of market integration. As reviewed by Fackler and Goodwin (2001), the most common are spatial arbitrage, the Law of One Price (LOP), and market efficiency. Spatial arbitrage holds the notion that the actions of traders ensure that the price difference between regional markets trading on a homogenous product is equal to transaction costs. The LOP states that markets in regions that are linked by trade and arbitrage should have a common and unique price, holding transaction costs constant. Supply and demand forces between the markets adjust to the shock and in the process, arbitrage eliminates the price difference below and above the transaction costs. The notions of market efficiency are used to motivate the study of market integration. Markets are assumed to produce accurate prices that reflect all available information about demand and supply conditions as well as transaction costs. The concept is also linked to Pareto conditions of allocation of resources.

Market integration is not a specific measure but rather a measure of the degree to which prices between two markets adhere to the LOP (Fackler & Goodwin, 2001). In ideal conditions, the LOP predicts that spatial arbitrage restores equilibrium prices to equality across well-integrated trading markets (Rapsomanikis *et al.,* 2003). Fackler and Goodwin (2001) also highlight that markets don't need to be directly trading with each other to be integrated. Price shocks are transmitted indirectly through the network, as long as they are in the same trading network.

Balcombe and Morisson (2002) broke down the concept of price transmission into three main components that define the degree of adherence to the LOP. First is co-movement and completeness, which implies that changes in prices in one market are effectively transmitted to the other markets at all points in time. Secondly is the dynamics and speed at which the price signal is transmitted. If the price changes are transmitted instantaneously between markets, the LOP is fully met and markets are said to be integrated. If the market signal takes a while but finally reaches the other market in the long-run, then price transmission is incomplete in the short run but complete in the long run. In this sense distinction between the long-run and short-run is necessary to determine the extent to which markets are integrated (Rapsomanikis *et al.*, 2006). The third component is the asymmetry in the price signal transmission which implies the size of the changes caused in the destination market. For instance, a small change in price in one market may lead to large changes in other markets, hence indicating asymmetry. Integrated markets exhibit desired characteristics of the three components which imply upholding the LOP, otherwise there are distortions to arbitrage.

The most common determinants of price transmission and the resultant market integration are trade barriers between markets, transfer costs, and competitive behaviors of firms (Alderman, 1992; Rashid, 2004; Hatzenbuehler, 2019). Trade barriers imposed between markets like tariffs and quotas influence the flow of price signals between markets. Firms with excess demand or supply are affected by bad tariff regimes by limiting the scales of production and consumption. Also, the scale of transfer costs between markets influences price transmission. The lower the transfer costs, the better the scale of price signal transmission, and vice versa. High transfer costs are commonly due to poor infrastructure like roads, poor communication networks, and insecurity between markets.

Market segments interfacing between rural and urban settings are the most affected by excessive transfer costs (Porteous, 2015). Markets within good infrastructure networks are more likely to be integrated (Badaine & Shivey, 1998). The non-competitive behavior of firms also imposes barriers to price transmission. For instance, oligopolistic behavior and collusion among firms may reduce price differences between markets to levels higher than transfer costs, causing limited trade. Competitive markets are the most ideal situation for integration, as price signals are transmitted without firms' interference.

There are known gains of integrated markets in the literature that are linked to efficient policy formulation and evaluation, technology innovation and adoption, and managing market risks. Policymakers evaluate the effectiveness of policies by observing the behaviors of firms. Integrated markets allow macro-level policies to change the incentives and constraints faced by micro-level decision-makers (Barrett, 2005). Firms become responsive to changes in demand and supply if a framework that facilitates effective transmission of price signals between markets exists. If firms fail to access distant markets, the gains from policy changes are lost because incentives to trade are diminished. This is because policies influence the behavior and interaction of market participants in response to the new trading environment (de Janvery *et al.,* 1990). Essentially, macro-policies often become ineffective when markets are not integrated (Barrett, 2005).

Integrated markets increase the likelihood of the adoption of new technologies in production so that excess demand from distant markets can be met (Barrett, 2005). The adoption of new communication technologies like mobile phones enhance distribution and marketing activities (Aker & Ksoll, 2016). For instance, actors using mobile phones easily exchange information across space within a short time. This makes price inquiries, orders, and coordination more efficient. Finally, when price signals are transmitted effectively, price variability causing demand and supply risks are controlled. Control of these risks incentivizes firms to plan production and consumption more effectively.

With the recent expansion of roads and communication networks connecting markets in pastoral areas, it is not only logical to expect price information to flow freely, but also for transfer costs between markets to remain relatively stationary. This then implies a possible existence of integration between market pairs and close adherence to LOP. If a weak price transmission persists in the current market environment, then other market structure distortions to arbitrage exist besides transfer costs linked to poor infrastructural connectivity (Acosta, 2019). This study provides a foundation on the nature and state of livestock market integration in the dryland markets of Kenya.

2.2.2 Prior Studies on Market Integration

Bizamana *et al.* (2015) conducted a study on market integration and price discovery for cattle in Mali. To do this, weekly data on nominal livestock prices from 10 livestock markets collected between May 2009 to April 2012 were used. Most of the markets were linked to the capital city via the main highway. Only prices from adult males of a breed called Zebu Peulh were used for analysis due to the consistency of data availability and homogeneity between markets. A Vector Autoregression (VAR) model was used to determine the level of market integration and the directed acyclic graph method was used to provide information on causal flow among the cattle market prices occurring in the same period. The results showed that more than 70% of the price variation was linked to market-level own-price shocks due to limited integration between markets. The observed low market integration among the markets was attributed to limited access to livestock markets due to poor roads and timely price information. The authors recommend further studies on the causes of stationarity among cattle prices in the region. They also recommended expansion of investments that reduce high transfer costs and cultural practices that limit trade.

Gitau and Meyer (2019) studied spatial price transmission in Kenya under four different maize policy regimes implemented at different times from January 2000 to December 2016. The main aim of the policies was to stabilize food prices in the country because maize is a staple in Kenya. Maize flows from surplus regions to main deficit areas which are mainly urban regions. The data was split into four sub-samples representing the policy regimes and Vector Error Correlation Model (VECM) was used to analyze the different policy effects. Johansen's maximum likelihood vector auto-regression approach was used to determine the cointegration between market pairs. The results showed significant differences in the effects of policy regimes on price transmission. Also, some policy regimes intended to manage price hikes were reported to have caused market distortion. High transaction costs in producer markets were due to poor infrastructure and levies charged. The authors recommended increased consultation and coordination between policy institutions, a review of import bans on Genetically Modified Food (GMO), and the distribution of fertilizers through the private sector.

Sassi and Mamo (2019) conducted a study on vertical price transmission in the white teff market between farmers in major production zones and retailers in consumption zones in Ethiopia. Monthly data used for the analysis was collected from July 2004 to January 2014. Estimation of integration and co-integration was done by using VECM and Threshold Vector Error Correction Models (TVECM). The results showed different features of market integration and co-integration across surplus regions. For instance, high prices that were harmful to consumers (referred to as positive price shocks) were observed in some regions. The authors provided several recommendations which included infrastructure improvement, establishing cultures and institutions that bring producers and sellers closer, and enhancing competitiveness in the supply of teff.

Arimoto *et al*. (2019) conducted a Randomized Control Trial (RCT) to investigate the effect of providing rice traders with price information on their behavior and resultant market arbitrage in Madagascar. Biweekly data on rice prices were collected from 10 major surplus districts, aggregated, and disseminated to traders for one year (August 2012 to August 2013). A simple Difference-in-Difference (DID) approach was used to estimate the coefficients for the average treatment effect of providing price information to traders. The results indicated that there was no significant impact on providing price information on traders' behavior and purchase price. The results supported an argument in other studies that information alone would not foster better arbitrage. The authors recommended the formulation of policies to support nonprice information, standardization, grading, and examination of other barriers that could limit market arbitrage.

Gloyal (2010) conducted a study on the impact of providing wholesale price information to Indian soybean farmers through information kiosks. Four data sources were used to conduct the empirical analysis comprising of two experimental groups. First, monthly prices of crops sold from April 2000 to September 2005. Second, yield and net area under cultivation of the crop from 1998 to 2004. Third, data on the date of installation of information kiosks. Fourth, annual administrative and demographic information at district level from a census of India in 2001 were used. Basic standard deviation and coefficient of variation were used to estimate the amount of price dispersion between the treated (accessing information kiosks) and the control. The results indicated a reduction in price dispersion after the introduction of internet kiosks. The prices of soybeans also increased at the farm level and farmers responded by increasing the amount of land under cultivation. The impact of providing information to farmers was linked to increased direct channels and a reduction in transaction costs as traders lost their traditional monopsony power.

Maina *et al.* (2013) conducted a study to analyse the level of market integration in livestock trade in Kenya using data on beef cattle prices for January 2006 to December 2010 from 10 spatially separated markets. Market integration and co-integration were estimated using Error Correlation Model (ECM) and Granger causality tests. Using Augmented Dickey-Fuller (ADF) and Phillip-Perron unit root tests for all market price levels, prices were found to be non-stationary. The results further showed more than one stochastic cointegration process, distributed based on the trading routes. For instance, markets along the northern rangelands route were integrated although the relationship was weak. The relationship was much weaker especially when the size of the market in the surplus regions became smaller, and farther from Nairobi, which was the major destination market. The authors attributed the outcome to poor market information flow and high transportation costs limiting perfect or stronger integration. The recommendations pointed to the improvement of infrastructure and policies in favor of the smooth flow of beef cattle from surplus to deficit regions.

In conclusion, there are limited studies on market integration targeting dryland markets. Even in other production systems, only a few focus on livestock. The bulk of the studies are on major staples produced. Most of the studies evaluate the state of market integration given a change in the trading environment triggered by targeted policy interventions. These studies provide fundamental checks and milestones to the effectiveness of policies intended to shape markets for commodities that significantly contribute to an economy. To reiterate the need for more inquiry, a review by von Cromon-Taubadel (2017) on price transmission and implications on African contexts, suggested that the current improvement in physical and institutional trade infrastructure in developing nations justifies more studies on market integration.

2.3 An Overview of Agricultural Market Participation

The achievement of economic growth through agricultural transformation is a pathway widely advocated but troubling to scholars and policymakers. Multiple solutions to the challenges faced have been linked to unstable supply and demand for inputs and outputs. Of particular concern to this study is the failure in supply response. This has been a consistent failure mainly characterized by a low local production surplus. Market participation has been one of the strategies advocated by scholars and policymakers to meet the supply deficits (Goetz, 1992; Megerssa *et al.*, 2020). A close and related concept in this space is market orientation. It refers to the extent to which a producer uses knowledge about the market (especially customers and prices), as a basis to make decisions on the three basic economic questions of what to produce, how to produce, and how to market (Kohli & Jaworski, 1990). Arguably, market participation allows for production surplus to be exchanged through trade and deficits to be filed through purchases from markets (Goetz, 1992). The extent to which this definition holds depends on the context being studied.

In the drylands of Kenya, pastoralists specialize in livestock production and thus markets are important in the disposal of production surplus and filling consumption deficits (Little *et al.,* 2014). Pastoralists sell milk and livestock in exchange for food items and cash for financing other expenditure like school fees, restocking, and medical care (Msangi *et al.,* 2014). They, however, face a mix of generic and peculiar market access challenges due to the state of economic, social, and environmental conditions they operate in. For instance, the average trekking distance from households to local and town markets is 10 km and 40 km respectively (Ng'ang'a *et al.,* 2016). The long distances have implications on the access to critical enablers of market participation e.g., dynamic market information. Insecurity due to inter-community social differences is also another challenge to market access (Schilling *et al*., 2012). Frequent droughts further worsen the situation by causing up to 60% unprecedented livestock losses and distress sales of animals whenever it occurs (McCabe, 1987; Opiyo *et al.,* 2016). Therefore, any effort that provides insights into how these challenges could be addressed is crucial.

2.3.1 Conceptual Framework of Market Participation

Most studies analyzing the determinants of market participation among agricultural smallholder households have focused on producers as sellers per se. This is because of the common belief that any policy that supports producers to receive high prices for marketable products has welfare gains to the participating groups and spillover benefits that include positive supply response in the following season (Jayne *et al.,* 2001). On recognition that smallholders have different characteristics even when producing a similar product, recent studies have further identified classifications of producers that include: "Net sellers", for those who sell more than they purchase; "net buyers", for those who buy more than they sell; and "autarkic" for those who balance between sales and purchases (Key *et al.,* 2000; Bellemare & Barrett, 2006).

Zanello (2012) further extended the three regimes by adding pure "buyers" and "sellers" to represent households that buy and sell at the same time. When constrained with cash at the beginning of the harvest season, they sell all and buy later, although at higher prices, or those households that have no liquidity constraints at the peak season when prices are low, buy, keep, and later sell when prices are high. Most analyses that followed have adapted these market regimes to define and analyse producer market participation regardless of the sub-sector.

There exists variation in levels of households' market participation behavior due to non-uniform exposure to transaction costs (Key *et al.,* 2000), market-level competitiveness, and spatial market integration (Fackler & Goodwin, 2001). The implications of the variations induce some households to opt out of market participation, increase vulnerability to price shocks, and weaken the formulation and evaluation of impactful economic policies (Barrett, 2008). A case in point is the 1990's smallholder poor response to market liberalization policies by developing nations that raised concerns about the role and power of markets in improving economic growth. It was also for this reason that many studies on market participation were on a rise in developing nations to understand the causes of the low response. Barrett (2008) is one of the popular studies that suggested interventions that target access to improved technologies and productive assets, facilitate farmer organization, and reduce the cost of trade as the preconditions of improving market participation.

Leveraging advances in Information and Communication Technologies (ICT) to reduce information asymmetry, especially due to the ubiquity of mobile phones, has been linked to improving market participation. Access to mobile phones can facilitate producers to send and receive market information more effectively across space and time (Aker & Mbiti, 2010). At the market level, some of the notable studies that have supported this argument include Jensen (2007) among fishermen in India; Aker (2010) among grain traders in Niger; Motu and Yamano (2009) among bananas, and maize producers in Uganda. Other evidence from Ethiopian smallholder grain markets shows that mobile phone ownership led to a 30% reduction in the conditional mean of a smallholder's price prediction error (Haile *et al*., 2019). In general, mobile phones allow the producer to access and assess critical market information like prices upfront, better access to inputs and technologies, reduce the cost of physically moving to search for information, and apt response to price risks.

These costs constitute a significant proportion of market transaction costs (Debsu *et al.*, 2016).

Other complimentary benefits to the access and use of mobile phones are associated with increased access to financial services (Baumüller, 2015). In Kenya, popular financial services through mobile phone-based M-Pesa, not only allow the transfer of money but also offer savings and loans in various ways that have shown transformation of livelihoods in local settings (Morawczynski, 2009; Bharadwaj, 2019). These services can enable pastoralists to sell their livestock when prices are high and save money in their M-Pesa accounts. Loan services can also be accessed through services like M-Shwari, which enable users to smooth their incomes and consumption (Bharadwaj, 2019). These benefits are expected to increase with more exposure to mobile phone use and have an impact on market participation.

Most of the studies on rural household market participation anchor on both utility and transaction cost theories. Utility theory views a producer's marketing behavior as an act to satisfy their own psychological needs, consumption, accumulate wealth, and leisure (Becker, 1962). They make decisions on what to produce, how much to produce, and where to sell in a manner that maximizes the return on their labor. These decisions are made with consideration of a set of known constraints such as cash availability, resource availability, and the production technology adopted by households. This implies that all costs incurred in maximizing utility must not exceed the income earned through sales of any tradable item at their disposal e.g., farm produce, labor, or other services. These endowments may technically include savings made by the household but assume limited borrowing and lending. Market prices, in this case, are also assumed to be exogenous and thus transaction costs can influence the decision on whether to participate in markets or not.

The transaction cost theory hinges on the distinction between fixed and proportional transaction costs (PTC) to explain the expected variation in household market participation. It states that smallholder households are encouraged to participate actively in markets if transaction costs are low. If these costs are high, smallholders stop using markets (Jagwe *et al.*, 2010). The new institutional economics approach shows that institutions have the capability of re-organizing the economic environment in a manner that changes the sources and nature of transaction costs. Reduction in transaction costs transfers gains to both buyers and sellers. Key *et al.* (2000) demonstrated that PTCs are the main cause of variation in market participation. Other pioneer studies on the link between transaction costs and market participation like Goetz (1991) argued that fixed transaction costs impede household market participation. Whatever the case, interventions that reduce transaction costs are deemed to increase market participation.

Mobile phone connections to rural areas in Kenya have generally been increasing in the past two decades but pastoral areas have lagged behind (Jack & Suri, 2014). Network connections were centered in major townships while rural areas, which are the main livestock production zones, remained poorly connected. Pastoralists with access to mobile phones but living in unconnected areas continued to travel to the spots with a network which were popularly called "network points" to convey or receive important messages. Even though such areas are not fully connected to now, a larger proportion is connected. Owing to the transformative capabilities of having access to mobile phones, pastoralists' market participation behavior is thus expected to have been influenced progressively by the heterogeneous network availability and mobile phone access.

It is generally hypothesized that agricultural market participation increases with increased exposure to market information. However, the transition from peasant farming into commercialization is characterized by increased net sales, the trend is usually unknown especially in pastoral settings. Typically, an increase in market price encourages households with a production surplus to sell. Studies such as Lybbert *et al.* (2004) point out that pastoralists do not use markets to regulate herd sizes and any increases in prices may not translate to increases in sales. This is counter-intuitive when commercialization is assumed to be the overall objective of a household. One of the plausible explanations is that the small numbers of sales observed are driven by consumption needs from the markets (Barrett *et al.*, 2006). Also, pastoral households do not take advantage of seasons with low market prices to purchase livestock. It is, therefore, important to establish the market participation regime that best describes households with exposure to market information through access to mobile phones.

2.3.2 Prior Studies on Access to Mobile Phones and Welfare Outcome

Zanello (2012) conducted a study on the effect of mobile phones and radios in reducing transaction costs that inhibited smallholder food crop producers from market participation in the dryland savannah of northern Ghana. The study categorised producers into buyers, net-buyers, autarchies, sellers, and net-sellers from a sample of 393 randomly selected households, surveyed based on the amounts of cereals sold and purchased. The relevant coefficients were estimated sequentially using Probit and ordered Probit models, for the decision to participate, and the Tobit model for determinants of quantity traded for each category. For each stage of estimation, correcting for selectivity bias and endogeneity was key, because market behavior is not a random process per se. The results showed that receiving market information through mobile phones had a positive significant impact on market participation, with a greater impact on households with surplus food crops. Also, radio ownership had a larger impact on the quantities of crops traded. Other factors like region, age, household head experience, distance to market, and off-farm income were significant. The author recommended efforts that go beyond ensuring simple ownership to re-orientation on how to use mobile phones in facilitating market participation. Furthermore, market information through mobile phones should be tailor-made to suit different users' abilities to interpret.

Parlasca *et al.* (2020) conducted a study on how mobile phones could improve nutrition among pastoral communities in northern Kenya. They used a six-round yearly panel survey data collected from 2009 to 2015. A sample of 924 households was purposely selected to reflect dimensions such as livestock production systems, agroecological conditions, market access, and ethnic composition. Panel Fixed Effects (FE) regression models were used separately to estimate the effect of five constructed mobile phone variables (i.e., 1=owns one and uses once in 12 months; 2 = own two or more and uses at least once in 12 months 3 = owns and uses every day; 4 = owns and uses once a week 5 = owns and uses once a month) on standard dietary diversity scores. The results showed that households' access to mobile phones improved dietary diversity mainly through better access to purchased food. The number of phones per household member, herd size, land size under cultivation, household size, and income levels were positive and significant. They recommended the promotion of mobile phone technologies in rural settings with poor access to markets while maintaining a low cost of calls and text messages. They further suggested that the expansion should be complemented by electricity and the improvement of network coverage.

Roessler *et al.* (2018) conducted a study on the impact of phone ownership on the household consumption behaviors of poor women in Tanzania. A three-arm RCT of no-cost basic handsets, smartphones, and a cash placebo as control, was designed and tested on a total sample of 1352 households. Observation data on the consumption behavior of the women was done over one-year (2016 to 2017). The data was collected across 11 clustered districts based on geographical diversity. The treatment effects were estimated using an Ordinary Least Square (OLS) regression. The results showed increased usage of financial services, financial inclusion, and household consumption. It was also noted that 30% of the participants lost their phones, and experienced a reduction in consumption, hence suggesting that phone replacement by poor households was difficult. The study recommended deeper considerations for poor households' mobile phone replacement costs to maintain positive consumption effects.

Asaka and Smucker (2016) conducted a study on the role of mobile phone communication in drought-related mobility patterns among Samburu pastoralists in northern Kenya. Twenty-one respondents drawn from a single community located 15 kilometers from the main town were engaged in a 2-day workshop. In addition, 13 key informant interviews were conducted with other members of the community. The data were analysed using qualitative methods. The results indicated a limited impact of mobile phone communication on grazing strategies and drought-related mobility patterns. The low impact was linked to limited trust in the information shared through mobile phones. The study recommended a wider spread of mobile phone network coverage to facilitate the constant sharing of information and to allow for the investigation of more grazing sites. Similar results were reported by Butt (2015) among the Maasai community in Kenya. They associated the limited use of information through mobile phones with strong pre-existing social rules that prohibit free access to grazing locations.

Tadesse and Bahiigwa (2015) conducted a study to examine the impact of mobile phones on farmers' marketing decisions and the prices they received in central Ethiopia. A multi-stage sampling technique was used to identify 1023 households from surplus producers of maize and wheat. The household survey was conducted in 2012. Four econometric estimation procedures were used; bivariate Probit for where-to-sell and whom-to-sell; ordered Probit for the frequency of selling; an OLS for the average price received and size of the transaction; binary Probit for farmer's use of a mobile phone for information search. The findings showed a weak impact of mobile phones on the target outcomes. Other important factors were landholdings, age of household head, education, distance to market, and access to electricity. They argued that the weak link was attributed to a lack of relevant content from information searches through mobile phones, and whenever relevant, it only benefited a few farmers and traders. However, it asserted that farmers were keen on market information search through alternative means, unlike mobile phones. The authors recommended the establishment of information centers at farmers' cooperatives or local agricultural development centers that provide reliable information and knowledge.

Aker and Ksoll (2016) conducted a study to determine whether mobile phones improved agricultural outcomes among crop farmers in Niger. Ninety-five village-level focus group discussions and key informant interviews, and 1044 household-level surveys were conducted between 2009 and 2011. An RCT with a treatment of mobile-phone enhanced capacity building was compared to control across the identified villages and households. A DID econometric estimation procedure was used to compare the outcomes of the intervention. The results showed a mixed impact where some treated households increased their crop portfolio while others did not increase their likelihood of selling. Households without prior market access were more responsive to the intervention unlike those with access to markets at baseline.

Furthermore, women in the treatment grew more crops even though they did not increase marketed volumes. The authors recommended more targeted efforts in engaging rural households with ICT technologies, so that appropriate groups are reached. They further cautioned that the impact of ICT would not be uniform everywhere and that learning how to use mobile phones was more important than actual access.

The overall perspective of the approaches and the successive studies explain why producers respond differently to market opportunities. It also outlines clear sources of deviation by linking household choices to the economic environment faced. From the market participation regimes discussed, policymakers desire to observe an increase in net sellers' marketable surplus together with the transition from autarky or net-buyers. This requires an in-depth analysis of the barriers and enablers of each regime. Therefore, to improve rural households' market participation, it is crucial to focus on the prospects of information technology, especially mobile phones. As such, increased access to digital platforms through expanding access to mobile phones and the internet spurs market connectivity (Deichmann *et al.,* 2016). How this work for heterogenous pastoral households was the main concern in this study.

2.4 An Overview of Data Collection Methods in Agricultural Rural Settings

The importance of timely and accurate data cannot be overemphasized when it comes to decision-making (World Bank, 2018). Whether these decisions take place in the social or environmental domains, at the household-, community or policy level, decision-makers require accurate information. Gathering such data is often expensive and time-consuming (Bitso *et al*., 2020). Conventional field survey methods have steadily evolved while seeking to meet the demand for high data quality by improving the quality of questionnaire design and implementation protocols. Primary data from focused group discussions, respondents' surveys, and key informant interviews collected through on-site trained data monitors or enumerators is the norm in agricultural rural settings (Nyariki, 2009). Designing questionnaires, recruiting, training, transporting, and managing enumerators are typical activities in this process. Each of the activities takes time and resources to set up and maintain, therefore posing notable weaknesses while at the same time exhibiting strengths that have helped it to remain the workhorse of agricultural and development economics (Grosh & Glewwe, 2000).

Embedding technology in the data acquisition process has relaxed significant constraints faced in using conventional data collection methods (Couper, 2017; Aborisade, 2013). While the use of these technology-enabled innovations has advanced in many economic sectors, the agricultural sector, especially the rural-based systems, which support millions of households in developing contexts, has lagged behind (Aker *et al.,* 2016). This has often led to the continued use of conventional field surveys, which can fail to meet the data requirements of practitioners and researchers. Some of the notable weaknesses include high costs of setting up and running surveys, limited flexibility in making changes to content and location of surveys, high turnaround time until usable data is obtained, and consistent data quality concerns mainly due to limited cross-validation of responses. The resulting data scarcity has slowed the achievement of development goals pursued to improve the livelihoods of poor communities (Bitso *et al.,* 2020). Therefore, technology-driven data collection protocols, such as crowdsourcing, that leverage the ubiquity of mobile phones in rural agricultural settings offer a great opportunity to reduce the constraints.

2.4.1 Crowdsourcing Digital Data Collection Innovation

The robust setting up of the crowdsourcing initiative begins once the decision to crowdsource has been made by the crowdsourcer. Hosseini *et al.* (2014) pointed out that crowd, crowdsourcer, tasks, and platform as the four pillars that make crowdsourcing initiatives. The pillars work together to deliver value to any entity leveraging crowdsourcing initiatives to tap crowd intelligence. The size of the crowd and skills required for a crowdsourcing platform to function effectively depends on the nature of the problem and the target community that the entity envisions getting solutions from. Also, the skills needed depend on the type of problem being addressed (Surowiecki, 2004). For instance, tasks that require transcription to one language would require homogenous crowds while transcription into different languages requires heterogeneous crowds. It is also important to note that crowds can be specific or anonymous (Neto & Santos, 2018). Specific crowds are those crowds whose individual information is kept by the crowdsourcer while the anonymous crowds have no individual information stored with the crowdsourcer. Specific crowds could be as narrow as in laboratories, university campuses, and specific geographic locations (Gupta *et al*., 2013).

Crowdsourcing can be implemented through approaches like micro-tasking. Micro-tasking is a digitally enabled data collection approach whereby complex surveys are broken down into a series of smaller tasks (Sveen *et al.,* 2020). Micro-tasking leverages the advances in digital and mobile technologies to draw on a large pool of data collectors that do not have to go through costly onboarding processes typical of conventional methods (Durward, 2020). The expansion in access and use of smartphones concurrently widens the pool of data collectors available for micro-tasking, provides a channel to recruit and remotely train potential contributors, and runs the micro-tasking platform itself (Mtsweni & Modiba, 2020).

Like other crowdsourcing approaches, data collection using micro-tasking might generate a lower data quality if contributors perform tasks under limited supervision (Gadiraju *et al*., 2015). Nevertheless, several data management quality protections are less available for conventional approaches (Neto & Santos, 2018). For example, the low cost of data collection provides a high density of observations that could be used to cross-validate data between contributors and flag outliers. Further, ICT-related features noticeable and non-noticeable by contributors, such as photo verification, geo-fencing tasks, temporal gates, and dynamic feedback, can be easily integrated into platform design. Any errors, either due to input error or shirking, are mostly avoided (Robert, 2019). Such features address the risk of lower data quality that data collectors might perform without on-site supervision.

Unlike conventional methods, micro-tasking is more flexible for adjusting and scaling the data collection activities (Kittur *et al*., 2008). To meet changing needs, networks of existing contributors could be activated or deactivated, and/or new contributors brought on board as needed. Further, data collection forms and related parameters can be adjusted and redeployed with little effort from platform administrators. New tasks targeting different subjects could also be launched on the same platform and performed together or independently with other tasks (Kittur *et al.*, 2008). The real-time adjustments on the content of tasks are a particularly relevant and important feature that allows convenient data gathering on the effects of acute events, such as drought or a pandemic with a scale such as COVID-19. While this feature further reduces the cost of setting up data collection, it also allows multidisciplinary approaches to projects by pooling together expertise in different subjects to use a single platform (Cuccolo *et al.,* 2021).

Surveys conducted through micro-tasking minimise transaction costs incurred to support enumerators in conventional data collection protocol (Edgar *et al.,* 2016). The costs avoided include transporting enumerators to reach survey subjects, lodging, and food for enumerators, and on-site supervision. Once the network of contributors is activated, rewards for tasks completed are the main cost incurred. Dynamic reward systems can be set up that incentivize participation. The contributors also have the freedom to perform tasks that gives them a maximum reward for their effort, while administrators can adjust rewards to incentivize increased collection of specific tasks (Allahbakhsh *et al.,* 2013). In the case where incentives are monetary, the activity also provides the contributors with an additional source of income.

2.4.2 Incentivising Participation in Micro-Tasking-Based Crowdsourcing

Money is the most common incentive used to pay for services provided (tasks performed) by crowd workers in world popular private crowdsourcing platforms e.g., MTurk, Upwork, Clickworker, and InnoCentive (Brabham, 2008; Kaufmann *et al.*, 2011). The monetary compensation applies to all forms of tasks, regardless of the level of complexity of tasks (Neto & Santos, 2018; Kittur *et al.,* 2013). It allows entities that use such platforms to attract and engage large numbers of crowd workers from any geographical dimension of interest (Feng *et al.,* 2016).

While monetary incentives are popular and seem linear to increase participation, their universal application across heterogenous contexts has been challenging

(Brabham, 2010). Moreover, monetary incentives even when having a positive influence, may not be exclusively enough to motivate contributors to participate (Feller *et al.*, 2012). Depending on the nature of the tasks, it is difficult to determine how much pay would motivate the desired level of outcome. Although Mason & Watts (2010) have pointed out that more pay leads to high performance in micro-tasking, it is also important to note that entities use crowdsourcing because it is meant to be cheaper than other related conventional initiatives (Paolacci *et al.*, 2010). In this sense cost-effectiveness is crucial. Despite the lauded benefits, monetary incentives can also be counterproductive in the sense that crowd workers are not entirely obligated to produce the best outcomes. Also, they can crowd out intrinsic motivation and become negative reinforcers once they are withdrawn (Benabou & Tirole, 2003).

There are several forms of pay-for-performance structure used in many fields including crowdsourcing initiatives (Feyisetan & Simperl, 2019). The most common ones are piece rates (each completed micro-task has its price) and flat rates (categories of tasks are lumped together into one outcome and then paid). Piece rate is common in micro-task-based crowdsourcing initiatives whereas flat-rate pay is commonly applied in the form of Rank Order Tournaments (ROT) in crowdsourcing tasks where the crowdsourcer chooses submissions meeting some set threshold and only top performers are paid (Malone *et al.*, 2010). ROTs are common in innovation challenges where there is an ultimate winner or set of winners. In practice, the payment structures influence the motivation to perform a task in different ways (Shaw *et al.*, 2011). For instance, Leazer (2000) argued that the piece rate payment structure is instituted to motivate a worker to increase their effort on work, but the assumption does not always hold. Hence, the challenge to crowdsourcing entities is identifying a suitable pay structure that suits specific crowdsourcing initiatives.

Besides monetary incentives, the use of feedback to incentivize participation is also common. Feedback is defined as additional information given to contributors besides the task during the crowdsourcing process (Lakhani & Wolf, 2005). It is commonly given to contributors participating in contests comprising two or more participants, and where one or a small set of winners are rewarded. It is meant to spur more effort or motivation and reorient the contributors to accomplish tasks more effectively. Aoyagi (2010) suggested that an optimal feedback policy maximises contributors' expected effort. Depending on the nature of the contest, feedback provided can be varied by time or content, or both. Mostly it is on current contributors' competitive position through leader boards or other forms of communication mainly to convey a signal of a provisional winner (Straub *et al.,* 2015).

The content of feedback could be additional information meant to improve contributors' skills both directly and indirectly linked to the task performed (Boons *et al.,* 2015). Other studies also point out that feedback provided generated anxiety, distraction, or stress leading to low-quality submissions (Ericksson *et al*., 2009). In other instances, when contributors are efficient, the positive impact of feedback may not be observable. In other studies, conducted in lab settings, the influence of feedback on performance was found to vary contingent on the payment structure (Ericksson *et al*., 2009).

In popular conventional field settings, the feedback provided was found to influence participation depending on the activity performed. For example, Azmat *et al.* (2016) reported that students' academic performance decreased when given feedback while Blanes and Nossol (2011) found an increase in performance in workplace settings. At the farm level, Curnel *et al.* (2011) gave some insights into the area by examining how farmers participating in crop modeling increase their performance in citizen science because they were provided with feedback that they found useful to predict their yields. Nonetheless, workers' demographic and institutional factors influenced the mechanism in which incentives affected participation.

2.4.3 Conceptual Framework for Participation in Crowdsourcing

Entities around the world using crowdsourcing initiatives desire specific outcomes just like in other online labor markets. As reviewed by Ghezzi *et al*. (2018), crowdsourcing is a "process" that requires the design of activities necessary to motivate crowd workers to decide to participate. These activities are- task design, task workflow, crowd management protocols, and incentive mechanisms. Design strategies for these activities vary depending on the nature of the crowdsourcing initiative. Nonetheless, a good design should increase the participation of contributors (Geri *et al.*, 2017).

High contributor participation is a critical success factor for crowdsourcing initiatives (Boons *et al.*, 2015). It enables the crowdsourcer to get the task submissions (data) easily and consistently from crowd workers at any relevant period. However, sustaining crowd motivation and participation is always a challenging endeavor for crowdsourcers (Shaw *et al.*, 2011). Hence incentives used need to be capable of motivating contributors to participate in crowdsourcing. In the absence of formal contracts, aligning incentives is fundamental because contributors have absolute freedom to choose whether, how, and the extent to participate in the crowdsourcing platform. Howe (2006) emphasizes the absence of formal obligation or mechanism to punish participation in crowdsourcing, which may increase the risk of moral hazards.

The concept of incentives and participation has been a popular subject in cognitive sciences and economics (Kalén, 2017). In cognitive sciences, there is a disaggregation of incentives into intrinsic and extrinsic forms in a bid to reconcile different forms of motivation in a market (Deci *et al.*, 2017). Recent studies on motivations pull together the content and process theories such as Maslow's hierarchy of needs (Maslow, 1943), job-characteristics-model by (Hackman & Oldham, 1976), and the expectancy theory by Vroom (1964), and others. The main aim of these motivation theories was to develop constructs that could explain motivation in different market contexts.

Agency theory is used in economics to study incentives (Holmstrom & Milgrom, 2012). The influence of incentives on markets has been found to differ across contexts despite the generic economic postulation by Benabou and Tirole (2003) that people respond to incentives. The common outcome targeted in both disciplines is agents' maximum performance. Information asymmetry between an agent and principal is the main justification for aligning incentives and the focus of agency models, while agents' behavior and responsiveness to incentive is the focus of motivation theories. Nyberg *et al.* (2016) argued that both theories predict a similar outcome, but the causal explanation differs. This study was anchored on the agency theory.

In the commonly used agency model, economic theory has always assumed that employees are economically rational in making choices using available information (Milgrom & Roberts, 1992). Despite critics that this assumption fails to account for economically irrational behaviors by Ariely (2009), the incentive maximization behavior is a plausible way to conceptualize incentives. Following the standard economic principal-agent theory (for example, Fama & Jensen, 1983), incentives are argued to raise performance by imposing a higher marginal cost on shirking or, equivalently, by lowering the marginal cost of performing. This follows that a contributor (agent) will be motivated to allocate time and effort to perform tasks if it is more beneficial in aggregate or gives maximum utility. For the crowdsourcer (principal), the value of the tasks performed should not exceed the cost of engaging the agent and thus he exhibits a cost minimization strategy.

In this study, the required participation of contributors by extension means high-resolution data availed through the digital platform that could be disseminated back to stakeholders to make reliable policy, marketing, and production decisions on dryland markets. To enable participation in task completion, contributors need to be motivated either from within themselves (intrinsic motivation) or externally by crowdsourcer (extrinsic motivation). Neto and Santos (2018) conducted a review of crowdsourcing publications and reported a high number of studies showing the use of extrinsic incentives (e.g., piece rates) than intrinsic incentives (e.g., enjoyment) while a few used a mix of both forms. Frey (2013) and Romaniuc (2017) both argued that although the two forms of motivation could work together to improve participation, the interaction is not always linear and depends on contexts. Extrinsic incentives crowding out intrinsic motivation is also possible and in other contexts, the introduction of additional incentives does not necessarily improve performance (Liang *et al.*, 2018). The concern of this study is to investigate how piece-rate monetary incentives could be complemented with market price information feedback to motivate pastoralists to participate in crowdsourcing for livestock market information.

2.4.4 Prior Studies on Contributor Participation in Crowdsourcing

Shaw *et al.* (2011) studied the influence of changing social and financial incentives on crowd workers' performance and the resultant quality of submissions on the MTurk platform. The study constructed RCTs that allowed varied treatments of the incentives. The amounts of money offered changed depending on the complexity of the task. The treatment effects were estimated by fitting an OLS into the data generated. The results showed that web skills, household size, and location (country of residence) were significant covariates regardless of treatment and randomization. The quality of submissions was high in treatments that financially incentivised peers to share and comment (a penalty was imposed on an individual worker when disagreed by peers) on each other's work. The study suggested that crowd workers would improve their performance when financial incentives are increased without affecting the quality of work. It also suggested that task framings improve the quality of performance and further recommend reward schemes that allow for overlaying social and financial incentives for greater output.

Straub *et al.* (2014) undertook a study on the influence of feedback on the performance of contributors in a tournament setting under MTurk. The tasks were simple and short, did not require special skills, and the payment was made on a Rank Order Tournament (ROT) basis. The contributors were a mix in terms of capabilities. They were informed about their relative strength to their competitors during the tournament process. The data were fitted into an OLS regression to estimate the difference in performances. The authors reported that giving feedback did not improve the performance of contributors; especially when a contributor is lagging in the tournament, feedback provision increased the chances of quitting the tasks. The contributors at the forefront of the competition, after giving feedback, tend to complete tasks with less effort when the competitors are weak. Furthermore, even those who were weak and decided to continue performing tasks put minimal effort into completion. The authors concluded that contributors perform worse under pressure and/or get distracted by constant feedback. The study recommended further testing of feedback in contexts where tasks are performed for a long period and by many participants.

Nov *et al.* (2010) studied the motivators in four forms of performance in online computing of communities sharing photos. The study used 276 surveys and system data from users at different stages of their tenure in the community. Continuous sharing was a critical success factor in such platforms and thus the dependent variable of interest was based on the number of photos uploaded per year, the number of unique tags applied, the number of contacts, and the number of groups per year of the users' photo sharing activity. The incentives of focus were enjoyment, commitment to community, self-development, and reputation gaining. These factors were measured on a 7-point Likert scale. Analysis of Variance (ANOVA) was used to estimate the difference in performance in each group. The authors reported a difference in the quality and quantity of submissions between new and experienced contributors. New entrants were keener on quality and skill development than the experienced group. The findings showed that contributors' tenure in the community significantly matters in performance and varies with the task type. They also argued that tenure does not lessen the effect of other important intrinsic and extrinsic factors. They recommended mapping motivators for different behaviors of contributors to allow crowdsourcers to target different groups with a relevant set of incentives.

Phang *et al.* (2015) studied the incentives to participate in an online policy deliberation forum among key stakeholders which included employees, customers, and citizens. The citizens were classified as either active (Contributors) or less-active (Lurkers). The difference in levels of outcome was estimated using OLS. They reported a significant difference in antecedents of performance among the two groups. Both intrinsic motivators (e.g., communality, collective benefits, and possession of civic skills) and extrinsic motivators (e.g., mobilization) affected the contributors' levels of participation. They further observed that high levels of education negatively affected lurkers' propensity to participate whereas women contributors with a low level of education or high incomes were likely to participate. They recommended different strategies to attract performance for swift contributors and lurkers.

Brabham (2008) conducted an online survey to assess the motivation of contributors, "iStokers", crowdsourcing for an online photo stock agency called "iStockphoto".

The contributors were expected to take photos and upload them to the company's website for clients to access and pay for their use. The constraint in this platform was having consistency in the supply of photos from contributors. Using correlation analysis, the author demonstrated that contributors could be from different wealth, races, and age classes. For instance, the mean age was 37.8 years and 77.6% had completed a United States associate degree. The contributors were drawn from different nations across the world. They further showed that monetary incentives were the most important source of motivation followed by other factors like skill improvement, fun, and reputational boost. They suggested that contributors' profiles matter in performance and thus crowdsourcers should consider professionalism and business for contributors as important as other motivating factors. They also argued that outputs from crowds could be as good as outputs from other co-creation processes like outsourcing among others.

Ye and Kankanhalli (2017) conducted a study to examine the influence of trust, benefits, and cost factors on contributors' performance in the most popular crowdsourcing platform in China called TaskCN, with over 3.6 million registered contributors and 61 thousand tasks. The contributors were recruited into the study through email and their performance on TaskCN was monitored for three months. Demographic and background information were included as control variables. Structural Equation Modeling (SEM) in the form of Partial Least Squares (PLS) was used for analysis. The results indicated a difference in motivation factors between intention to participate and actual participation. Also, monetary incentives, trust, work autonomy, enjoyment, and skill enhancement were important in enhancing performance while cognitive effort inhibited participation. Trust was also found to mediate the effect of monetary incentives on contributors' participation. The study suggested that crowdsourcers could boost performance by encouraging streams of benefits to the contributor that include monetization strategies like sharing profits. Virtual rewards like badges or points for collection could enhance enjoyment.

Ericksson *et al.* (2009) conducted a real effort experiment to study the influence of varying feedback time on participants' effort under piece rate and ROT payment structures. The three feedback regimes included: no feedback, feedback given halfway through the experiment, and continuously updated feedback. The study used an OLS for analysis. The results showed that feedback on average does not improve performance for all categories of contributors in both payment structures. However, bottom-ranking contributors under rank-order tournament payment structures did not give up, even when the marginal benefit to the effort was zero, while those in the front did not reduce their effort on the tasks. In both payment structures, feedback on relative performance reduced the quality of submissions from bottom performers. It was observed that feedback showing performance comparison between contributors under the piece-rate payment structure was trivial. The authors suggested that feedback should not be a priority for a crowdsourcing entity regardless of payment structure, not only because of its limited impact on performance but also because it is costly.

In conclusion, crowdsourcing initiatives are used across the world to tap knowledge from a large group of people. As observed in the literature, different problem areas use crowdsourcing with varying levels of success. For general-purpose platforms, for instance, MTurk, the solution seekers target general aspects that cut across the world and success is evident. Specific-purpose platforms, whose geographical coverage was narrow, filled the gap by engaging crowds on problems peculiar to specific contexts. Nonetheless, each crowdsourcing initiative has its peculiarities in contributor participation and performance. Different crowds engaged, at any level, are motivated by varying forms of incentives that determine the success of the crowdsourcing initiative.

This study contributes to the growing but inconclusive body of knowledge on incentivising contributors' participation in crowdsourcing by overlaying market price information feedback on piece rate monetary incentives. Furthermore, the study provides insights into the potential of crowdsourcing in agricultural markets situated in rural areas, specifically in the livestock markets situated in the dryland. It also provides alternative pathways to the recurrent challenge of market information dissemination to pastoral market stakeholders by using market price information feedback as an incentive for obtaining timely and accurate data through a mobile-phone-based micro tasking.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses the theoretical framework, econometric specification, research design, estimation procedures, study area, sampling, and the considered variables used to study the three objectives outlined in chapter one. The section provides details on how the central questions in each of the outlined concepts were addressed. All three facets of the study are geared towards providing a comprehensive view of the dryland digital landscape and its implications for agricultural market development.

3.2 Livestock Market Integration

3.2.1 Theoretical Perspective of Market Integration

The Enke-Samuelson-Takayama-Judge (ESTJ) model (Enke, 1951; Samuelson, 1952; Takayama & Judge, 1971) is commonly applied in studies on spatial market integration. The model is linked to the spatial equilibrium economic framework. The ESTJ model describes multiple equilibrium levels that may exist in two markets based on arbitrage conditions and tradability arrangements. The generalized mathematical forms of the model are described as follows.

$$P_t^b < P_t^a + \tau_t^{ab} \quad \text{if } q_t^{ab} = 0 \qquad 3.1$$

$$P_t^b = P_t^a + \tau_t^{ab} \quad \text{if } q_t^{ab} \in (0, q_t^z) \qquad 3.2$$

$$P_t^b > P_t^a + \tau_t^{ab} \quad \text{if } q_t^{ab} = q_t^z \qquad 3.3$$

Where P_t^b and P_t^a are the prices in market b and a in-time t respectively; τ_t^{ab} is the transfer costs from the market a to b at time t. q_t^{ab} is the physical flow of trade between the markets a and b in time t while q_t^z represents the maximum allowable trade volumes (mostly applicable to international trade where quotas are imposed) between the market pairs. The size of transfer costs between the market pairs determines the different equilibrium conditions. All three equilibrium conditions imply both firm-level profit maximization and long-run competitive equilibrium at the market level (Barrett, 2008).

The three equations represent price relationships in a range from the absence of market integration and strict adherence to the LOP. The spatial price difference between the two markets in equation 3.1 is less than the transfer costs. In this state, there are no arbitrage opportunities for traders to explore, hence no trade. Equilibrium condition with strict equality in equation 3.2, assumes a price difference between market pairs to be equal to transfer cost. This represents adherence to the LOP form of competitive equilibrium. Market prices under these conditions move together perfectly whenever there are demand and supply shocks. The equilibrium condition in equation 3.3 shows market price difference higher than transfer costs implying unexploited arbitrage opportunities. Markets in such conditions are said to be inefficient and have imperfect competitive equilibrium despite the occurrence of trade. Economic policies are formulated to fix the causes of these inefficiencies. Spatial market integration occurs when the ESTJ equilibrium conditions hold, irrespective of whether trade occurs or not.

Ideally, the variables needed for comprehensive analysis using the ESTJ framework are prices, transaction costs, trade volumes, and trade volume quotas (Barrett, 1996). The approaches used to analyse spatial market integration are classified into three categories depending on the data type(s) used; the static price correlation approach, dynamic methods, and regime-switching methods (Barrett, 1996). The static price correlation approach is purely based on price data and measures integration by estimating the extent to which prices of a homogenous commodity in two markets correlate. Similarly, dynamic models rely on price data alone, but are not limited to a pair-wise test and distinguish between short- and long-term integration. These methods include Granger causality (Granger, 1969), the Delgado variance decomposition (Delgado, 1986), the Ravallion model (Ravallion, 1986), and the standard cointegration methods (Engle & Granger, 1987). Lastly, regime-switching models, which is an advancement of the first two, combines price and transaction cost data at their minimum and analyze integration in a non-linear approach. Methods in this category include the Parity Bound Model (PBM) (Baulch, 1997a), the Markov switching model (Hamilton, 2001), and the Threshold Autoregressive (TAR) model (Balke & Fomby, 1997).

Generally, the hierarchy in these models lies in the underlying assumptions, nature of trade, and the data requirement for analysis. Also, peculiar characteristics in the trade of homogenous commodities between markets like having unidirectional or bidirectional trade flow, changing transaction costs, having cycles of occurrence and non-occurrence of trade, makes the models unable to give true estimates but have led to advances that incorporate these conditions (Fackler & Goodwin, 2001). Modification of the models has been based on empirical realities and their ability to meet the ESTJ logic of spatial equilibrium models (Barrett & Li, 2002). In most studies targeting agricultural markets in developing nations, price data is commonly used because of limitations in getting other data types. However, there are a few exceptions (Barrett & Li, 2002) that extended PBM to accommodate both market integration and competitive market equilibrium analysis. In addition, Negassa & Myers (2007), and Zant (2012) modified the model by relaxing the assumption of constant regime probabilities over time.

3.2.2 Econometric Specification of Spatial Market Integration

In this study, dynamic models were explored for analysis. This was based on the availability of the data requirement of the models, and the nature of livestock trade in the target pastoral areas. If time-series data on transfer cost could be available over the desired period, then the regime-switching models, in the form of PBM would be the most preferable. However, like other agricultural product data, livestock trade data is hardly complete. Dynamic models are designed to analyze integration in such circumstances. In the end, the interest of the study was to understand the nature of the long-run price relationship between dryland markets.

The approach of market integration using dynamic models is the advancement of the traditional bivariate correlation. Cointegration analysis, developed by Engle & Granger (1987), is the most common procedure used in dynamic models. The model assumes that price series are non-stationary. It also considers delays in price shock transmission across markets due to transportation delays, delivery lags, and traders' lack of perfect foresight of market conditions. These delays are practical and common in agricultural markets having surplus markets in rural settings. Fackler and Goodwin (2001) argued that the non-stationarity of price series in the agricultural commodity market was a reality that needed consideration, and thus any method that ignored it, gave an erroneous measure of market integration.

Cointegration analysis is a stepwise procedure. Trend analysis using a graphical method is the preliminary test of stationarity in time series data. It gives a picture of price trends of interest. The second step is a more precise and formal statistical test of stationarity known as unit root. This is accomplished by using the standard Augmented Dickey-Fuller (ADF) test. Other methods like Phillips-Perron (PP) and Kwiatkowski-Philips-Schmidt-Shin (KPSS) are also used for validation due to the generally low statistical power of each of the methods to reject the null hypothesis of stationarity. The main strength of the ADF test is its ability to add lagged independent variables into the unit-roots regression test to take care of any possible serial correlation (Gujarati, 2003). If the unit root test equation consists of time series data having characteristics of a random walk with drift and stochastic trend, the ADF test would consist of testing the following regression.

$$\Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \sum_{t=1}^{m} \alpha_i \Delta Y_{t-i} + \varepsilon_t \qquad 3.4$$

Where ΔY_t is the first difference in the price series, ΔY_{t-i} is the change in lagged price series, β_i ,δ and α_i are coefficients to be estimated, m is the number of lags to be included in the model, and ε_t is a pure white noise error term. The number of lagged differences to include is determined empirically, the idea is to include enough terms so that the error term in equation 3.4 is serially uncorrelated (Gujarati, 2003). The key test is whether $\delta = 0$ i.e., if $\delta = 0$, then we have a unit root, meaning the price series under consideration is non-stationary. ADF provides a mechanism of statistically knowing whether $\delta = 0$ or not. Depending on the estimates of β_i , the ADF reduces to forms that correspond to price series that either exhibit random walk or random walk with drift, or random walk with drift and trend. PP and ADF are similar in procedure, but PP largely follows non-parametric statistical methods to control autocorrelation. KPSS follows a langrage multiplier procedure. There was a preference for the ADF procedure, but all tests were conducted to test the robustness of the results.

The outcome of the unit root test shows whether two series are stationary or not. If found stationary then the coefficients can be used for prediction and if not, a transformation is required to make the time series stationary. This can be done through detrending or finding the first difference (Gujarati, 2003). The whole idea is to ensure that a spurious regression is not run by using non-stationary time-series data. For instance, integration of order one (I (1)) variables should be differenced before they are used in linear regression models, whether they are estimated by OLS or instrumental variables (Wooldridge, 2009). The notion of cointegration allows regression of variables I (1) to obtain estimates of long-run relationships between time series data. It involves the estimation of the following equation which is commonly called the cointegration equation.

$$y_t = \beta_1 + \beta_2 x_{2t} + \mu_t \qquad 3.5$$

Where y_t is the dependent variable (mean livestock prices for deficit market) at time t, β_1 is the constant, x_{2t} the independent variable (mean livestock price for surplus market), β_2 is the cointegration parameter, and μ_t is the error term, which is often measured for unit tests as mentioned earlier. Cointegration tests consider the time-series properties of the residual term μ_t. If the residual is stationary, the implication is that, although prices of livestock between the markets wander extensively on their own, they are linked in a long-run stable equilibrium (Fackler & Godwin, 2001).

To establish the statistically sound long-run relationship, depicted by the value of the cointegration parameter, two popular tests suggested by Engle and Granger (1987) called the Engle-Granger test, and Johansen (1988) called the Johansen test were used. The Engle-Granger approach relies on residuals while Johansen's (1988) approach relies on the relationship between the rank of the matrix and its characteristic roots (eigenvalues). Engle-granger also requires the normalization of all price-series, that is, equation 3.6 be differentiated once I (1) but the Johansen approach does not require it. There are other tests like the cointegrating regression Durbin–Watson (CRDW) test that are also used. All the discussed tests are meant to limit using estimates from a spurious regression (Gujarati, 2003).

The next step, involving the establishment of short-run equilibrium, the magnitude of price change, and speed of price adjustment between market pairs, was done using the Vector Error Correction (VEC) framework. The VEC framework was first used by Sargan and later popularized by Engle and Granger (Engle & Grange, 1978) to correct for disequilibrium depicted by the error term in equation 3.6. It also provides a mechanism to establish the direction of Granger causality both in the short- and long-run (Granger, 1988).

If two markets are integrated, their relationship can validly be explained using the VEC framework as follows.

$$\begin{pmatrix} \Delta p_{1t} \\ \Delta p_{2t} \end{pmatrix} = \begin{pmatrix} \mu_1 \\ \mu_2 \end{pmatrix} + \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} (p_{1t-1} - \beta p_{2t-1}) + A_2 \begin{pmatrix} \Delta p_{1t-1} \\ \Delta p_{2t-1} \end{pmatrix} + \dots\dots + A_k \begin{pmatrix} \Delta p_{1t-k} \\ \Delta p_{2t-k} \end{pmatrix} + \begin{pmatrix} v_{1t} \\ v_{2t} \end{pmatrix} \quad 3.6$$

Where v_{1t} and v_{2t} are the *iid* disturbance term with zero mean and constant variance. The operator Δ denoted that the I (1) variable meets the stationarity condition. The parameters in matrices $A_2 \dots A_k$, measure the short-run effects, while β is the cointegration parameter that characterizes the long-run equilibrium relationship between price pairs. The price levels enter the model as a single entity $(p_{1t-1} - \beta p_{2t-1})$ and thus reflects any divergence from equilibrium. The vector, $\begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix}$ contains parameters commonly called error correction coefficients. It measures the speed at which the markets return to equilibrium. Most importantly, the proximity of α_i to one is used to assess the extent to which, transaction costs and other interventions delay full adjustment to the long-run equilibrium.

3.2.3 Estimation Procedure of Cointegration Dynamic Analysis

There are several steps and equations estimated in determining the spatial integration of markets. All the estimation procedures were done in STATA statistical software. Price trends analysis was done using the time series command for line graphs- *tsline*. The ADF procedure for testing stationarity was done using the *dfuller* command. The next step was obtaining the optimal lag length for the model using *varsoc* command. This was followed by a Johansen cointegration test with the optimal lags obtained using the *vecrank* command. If there was no cointegration, the unrestricted VAR model would have been estimated (using *var* command). In this study, the Johansen cointegration test confirmed the presence of cointegration and thus VECM (using *vec* command) with optimal lag length was estimated. All diagnostic tests: autocorrelation, normality, and model stability were estimated using *vecmar, vecnorm,* and *vecstable* commands respectively.

3.2.4 Study Area and Data Sources

Pastoral livestock markets in northern Kenya were the focus of this study, as described in detail in sections 3.4.6. The study was conducted in three purposively selected counties in northern Kenya: Marsabit, Samburu, and Isiolo. Six markets, comprised of four intermediate markets (Isiolo, Lekuru, Merille, and Moyale) and two feeder markets (Korr and Archers-Post) in the three counties were selected. These markets are geographically dispersed to represent a wide catchment area and two important trading routes (Alarcon *et al.,* 2017). Moyale, Korr, Merille, Acherspost, and Isiolo markets are in one trading route. They are also located along the Moyale-Isiolo Tarmac road—which was the only tarmac road in the region.

Korr market is located 50 km off the tarmac road. Lekuru market represented markets on a different route i.e., the Baragoi-Nyahururu trading route. It is also one of the biggest in terms of livestock traded and the diversity of traders in the trading route. Most of the sampled markets operate on predetermined weekly cycles, with a few in major towns (Moyale and Isiolo) operating daily but having a single larger market day each week. The supply of livestock during market days is usually in the hundreds but can be much larger or smaller in some cases. Variation by animal types supplied in a market day also exists. The distribution of the markets is shown in Figure 3.1.

The data on livestock prices were obtained from the crowdsourcing initiative described in sections 3.4.1 and 3.4.6. However, data for this objective was collected over a longer period i.e., between November 2019 to October 2020. The crowdsourcing approach was adopted as an innovative alternative to previous data collection systems that have failed in providing reliable and consistent data from these markets over a long period (Stuth *et al.*, 2006; Tollens, 2006). This approach provided reliable high-frequency data that matched the weekly cycles of trade in the sampled markets. The livestock prices of available animal types were captured following standardized livestock quality dimensions indicated by the Kenya Bureau of Standards (KBS). To cover the quality heterogeneity within livestock type traded, and to have representative data, protocols to ensure multiple submissions per animal type were established.

The high-frequency data generation process used was to overcome weakness associated with analysis based on aggregates over a longer span e.g., biweekly, monthly, quarterly, etc. Hence, providing a clearer picture of trade efficiency and market integration (Hooker, 1993). Moreover, if markets were integrated, there was no logical reason to believe that prices would take a long time to be transmitted since markets occur on weekly basis, and with almost the same network of traders, even up to the national terminal markets.

To ensure consistency and completeness, data from animal types present in all sampled market locations during all weeks were used for analysis. In this case, prices for goats met this criterion. No clustering based on goats' quality, age, or sex was done because the data captured was deemed representative of each cluster. All data submitted from each sampled market were validated and aggregated. Weekly price averages were calculated from all aggregated submissions from each market and used for analysis.

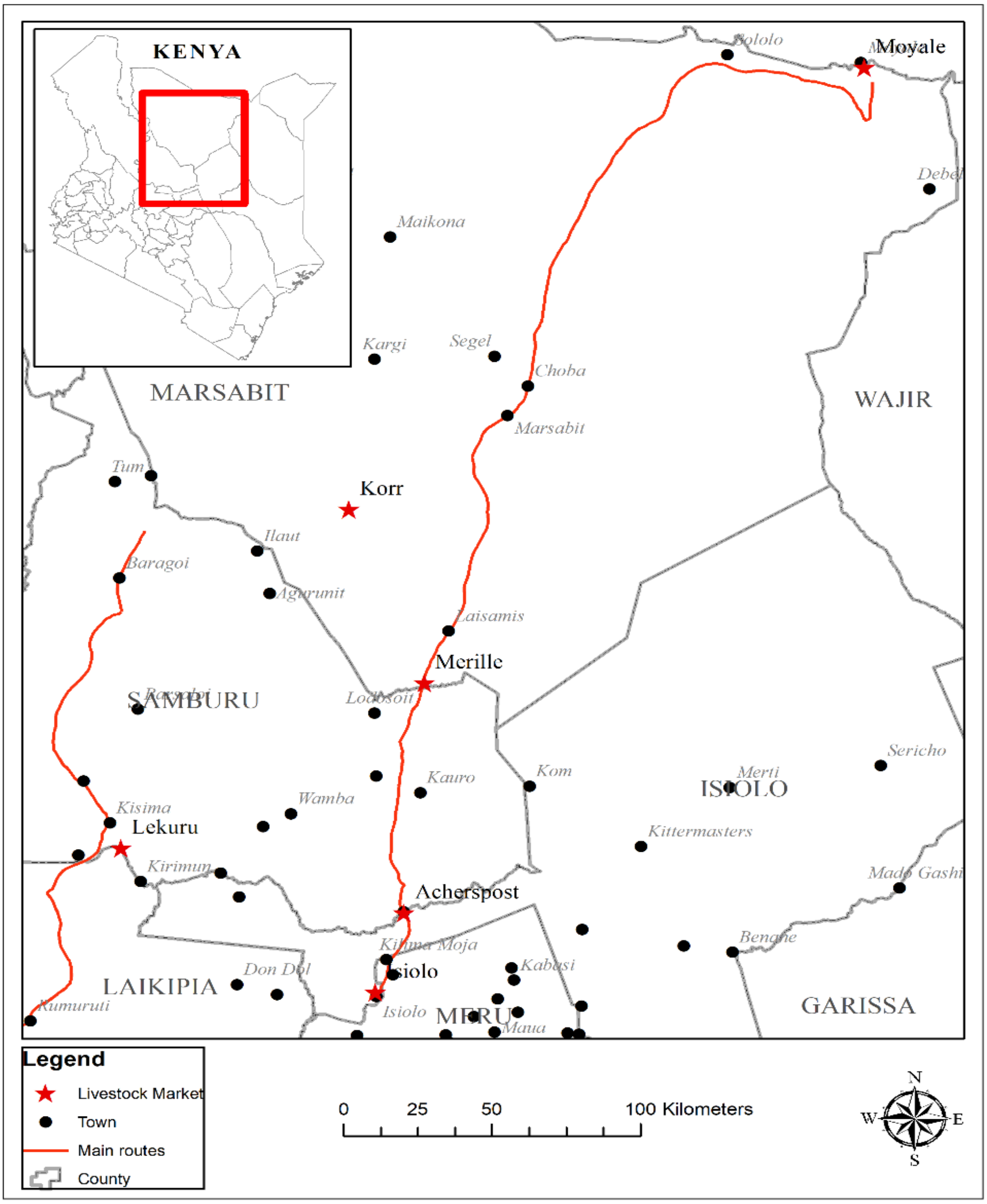


Figure 3.1: Location and distribution of the six sampled markets

3.3 Pastoral Households Market Participation

3.3.1 Theoretical Perspective of Household Market Participation

The study aimed at establishing whether an increase in access to mobile phones affects the market participation of pastoralists. While both utility and transaction cost theories outline the expected behavioral change when information access is varied, this study adopts the utility theory framework to explain the expected response to market participation given access to mobile phones. The common hypothesis of households maximizing utility is upheld. This leads to choices of regimes in market participation i.e., net sellers, autarkic and net buyers, representing a trichotomous theoretical nature of decisions made by households to interact with markets.

Transaction costs experienced by households in marketing raise the prices effectively paid by the buyer and lower the prices received by the seller. With this experience, a household chooses its market participation regime depending on utility derived from selling or buying livestock from the market or remaining self-sufficient. Within a household, access to mobile phones has an impact on transaction costs by allowing the household to search for market information that helps to make trading decisions (Zanello, 2012). Essentially it reduces the market power of any intermediary (e.g., a broker) between the household and the true market price.

The household's utility from participating in each market regime is not observable but the decision to participate is observable i.e. $(y=1)$ for the decision to participate and $(y=0)$ for the decision to become self-sufficient. The household choice of market regime j, with threshold parameters ∂^* to be estimated (mostly defined by the differences in sales and purchases from the markets) together with other parameters in the model can be represented as follows.

$$Y_{ji} = \begin{cases} 1 \; if \; Y_{ji}^* \leq \partial_1 \\ 2 \; if \; \partial_1 < Y_{ji}^* \leq \partial_2 \\ 3 \; if \; \partial_2 < Y_{ji}^* \leq \partial_3 \end{cases} \qquad 3.7$$

Households must make a discrete choice of whether to participate in a market or not, then if the result is positive, the amount to purchase or sell is determined. Whether this decision is sequential i.e., the decision to participate is made separately with the amount to trade (buy or sell) or simultaneous i.e., both sets of decisions are made at once well in advance, depends on the context being studied (Goetz, 1992; Key *et al*., 2000; Bellemare & Barrett, 2006). In either case, the participation decision can be represented by a simple model as follows.

$$Y_{ji}^{*} = \beta_{ji} X_{ji} + \varepsilon_{ji} \quad 3.8$$

The Y_{ji}^{*} represents the latent dependent variable that describes the i^{th} household's market participating in regime j (1=net buying, 2=autarkic, 3= net selling). The regimes are defined by the differences between sales and purchases from the market; if the difference is positive then the household is categorized as a net seller, if negative then a net buyer, and if zero then autarkic. The regimes are on an ordinal scale. X_{ji} are the vector of covariates, including access to mobile phones, influencing participation in the j^{th} market regime, β_{ji} represents the parameters to be estimated, and ε_{ji} is the error term.

3.3.2 Econometric Specification of Household Market Participation

The models used to analyse market participation have evolved since the pioneering work by Goetz (1992). One dimension of the changes has been on how the outcome variable is modeled i.e., either as a binary choice or as an ordered scale. The other dimension is whether to model participation as a joint or a sequential decision. Consequently, two-step models have been widely used to estimate the factors determining household market participation behavior. This is because of the premise that the market participation decision process starts with a discrete process then followed by a continuous one (Barrett, 2008). Otekunrin *et al.* (2019) provide a comprehensive review where they found that the two-step decision-making process is commonly estimated using the Heckman model and Gragg's Double Hurdle model.

In other studies, triple hurdle models are used, for example in Zanello (2012) and Okoye *et al*. (2016). The additional step from the latter group comes from the premise that the first step comprises the usual selectivity into participation or non-participation, followed by allocation into the three participation regimes, and the final determination of the intensity of participation by estimating the quantities traded.

Further consideration of whether the market participation decision is made separately or sequentially led Bellemare and Barrett (2006) to test this hypothesis using data obtained from pastoralists in Kenya and Ethiopia. They found evidence in support of a sequential decision-making process using an ordered Tobit estimation procedure and Heckman correction for standard errors. Given the similarities in context, this study adopted the ordered Tobit procedure that allows for multiple ordered values (net buyer, autarkic, and net sellers), and continuous outcomes for the number of sales and purchases to be estimated. The reduced form of the ordered Probit model, the first stage of ordered Tobit, takes the following empirical structure.

$$Prob\ (y_{it} = 1, y_{it} = 2, y_{it} = 3) = (\beta_1 DMP + \beta_{2t} X_{it} + \beta_{3t} Z_t + \mu_i + \varepsilon_{it}) \quad 3.9$$

Where, y_{it} is the market participation regime of the i^{th} household at the time t for the three regimes. The parameters of the phone access duration variable (DMP), which was the main variable of interest in the study, were estimated together with other control variables. Z_t represents the time dummies (yearly) and μ_i captures the household fixed effects. Time (survey round) was included to control for changes that may have occurred e.g., road networks. Estimation of the second stage of the ordered Tobit was done by replacing the ordered outcome in equation 3.9 with the continuous outcome.

The analysis of market participation is typically confronted by endogeneity and selectivity problems (Tadesse & Bahiigwa, 2015). In this case, one prospective endogeneity may come from the possibility of market participation affecting access to mobile phones, hence reverse causality. To counter this, the spatial variation in the deployment of communications towers that provide service for cellular phones was used as an Instrument Variable (IV) for access to mobile phones. Data on the year the sublocation was connected to the telecommunication network was used as the IV. This was based on the premise that the decision to set up communication towers was made by mobile service providers and thus not impacted by the households' marketing decisions.

The instrument was also tested for exclusion criteria and validity, besides testing for the presence of endogeneity while being cognizant of the effect of inflating the asymptotic variance if IV was used in the absence of endogeneity (Wooldridge, 2003). Regarding selectivity, pastoralists do not randomly allocate themselves to the various market participation groups. An Inverse Mills Ratio (IMR), which is the generalized residual for access to mobile phones, was calculated and used as a variable in the second part of the estimation as applied in (Bellemare & Barrett, 2006).

3.3.3 Experimental Design and Data Variables

The study followed a natural experiment of the adoption of mobile phones among pastoralists over 11 years as depicted in the panel data collected for seven rounds from 2009 to 2020. The study variables were computed or obtained from the collected data. The dependent variable used in this study measures the pastoralists' livestock market participation. Livestock offtake and intake through sale and purchase were the focus of this study. Details of all animal types herded by the household within the reference period were captured. The seasonal entries collected in each survey round were aggregated into 12-month-totals for each survey round.

Sales and purchases for small ruminants (goats and sheep) and large ruminants (camel and cattle) were aggregated separately. Offtake and intake of livestock through informal channels such as loans, slaughter, borrowing, and other traditional mechanisms were not included in the computation of market participation outcomes. This allowed for household market participation to be accounted for strictly using livestock purchased or sold (Bellemare & Barrett, 2006). These data were used to compute market participation in two parts, the first outcome comprised ordered categories, and the second was continuous (Key *et al*., 2000).

Market participation category: This was the first part of the outcome that used households' purchases and sales data to compute the market participation categories. This outcome is composed of three ordered categories. Those households that purchased more than they sold were categorized as net buyers and given a value of one. It also included households that only purchased livestock without necessarily selling i.e., have zero sales. The second category is comprised of those households with sales equal to purchases. These households were categorized as autarkic and given the value of two. It also includes households that did not sell or purchase any livestock. The third group consisted of those households that sold more than they purchased. These were categorized as net sellers and given a value of three. This category consisted of households that sold livestock without necessarily purchasing. Separate market participation categories for small ruminants (SR) and large ruminants (LR) were computed.

Market participation intensities: The second outcome variable was (1) a measurement of the total tropical livestock units (TLUs) of livestock sold and (2) the total TLUs purchased by each household during the 12 months preceding each survey round. Only those households that had positive sales and purchases were considered in determining the intensities of market participation. Like the ordered outcome, separate values for SR and LR were computed.

Access to mobile phones was the main variable of interest. Access was measured by the number of years (duration) households have accessed mobile phones. This was self-reported data from the households. Other important controls were also included, based on the context studied and those deemed important in similar studies. The total livestock herded and/or owned at the time of the survey was collected. This data was converted into TLUs and aggregation for each household in each survey round was computed. The settlement type of the pastoral households was categorized into three: fully sedentary, partially sedentary, and nomadic. Considering fixed market locations, mobility is a key non-price factor that influences pastoralist market access (Little *et al.*, 2014). Therefore, the degree of mobility in each settlement type was expected to positively affect market participation.

Remittances received and/or given were measured in monetary terms. These values were used to construct three categories using similar logic as the market participation outcomes. For poor households, remittance received reduces the need for frequent livestock sales to finance consumption expenditure. Remittances may also stimulate investments for non-poor households as it beefs-up the resources available for non-consumption expenditure (Sekabira & Qaim, 2017). Distance from households to the main market in the region was measured in kilometers using Global Positioning System (GPS) data obtained during the survey. Households further away from these markets were constrained by both information asymmetry and high transaction costs. This reduces the likelihood of active market participation (Muto & Yamano, 2009) and encourages households to be self-sufficient (Sebatta *et al.*, 2014).

Market participation intensities: The second outcome variable was (1) a measurement of the total tropical livestock units (TLUs)

The financial literacy index was computed from responses to questions that tested the pastoralists' knowledge of financial concepts. A higher score was expected to enhance market participation or encourage diversification. Income data from both livestock and non-livestock sources were also obtained. A livestock income ratio was computed to distinguish the degree of reliance on livestock for income. Gender, age, and education of the household head as well as the household size, were also included. A comprehensive list of covariates included in the analysis is presented in Table 3.1.

Table 3.1: Explanatory Variables Used in the Analysis of Household Market Participation

Variables	Variable labels, values, and values labels	Hypothesised effect
Household access duration	The number of years any member of a household accessed mobile phone; years	(+)
Connectivity duration	The number of years the sublocation has access to network coverage; years	(+)
Household size	Total number of household members; headcount	(+ /-)
Years of schooling	The year of schooling completed by the household head	(+)
Financial literacy index	The knowledge of the household head in basic financial concepts; index	(+)
Age	Age of the household head; years	(-)
Financial savings	Whether the household has financial savings; 1 = yes, 0 = no	(+/-)
Marital status	Whether the household head is married; 1 = married, 0 = not married	(+/-)
Group membership	Whether the household head is a member of any group; 1 = yes, 0 = no	(+)
Gender	Gender of the household head; 1 = male, 0 = female	(+ /-)
Livestock income ratio	The proportion of livestock incomes in the total household income; ratio	(+)
TLUs herded	The total count of livestock herded by household; TLUs	(+)
TLUs owned	The total count of livestock owned by household; TLUs	(+)
TLUs traded	The total count of SR and LR sold or purchased	(+/-)
TLUs informal	The total number of TLUs exchanged; offtake and intake	(+/-)
Settlement category	The general description household settlement category; 0 = Fully settled, 1 = nomadic, 2 =partially settled	(+ /-)
Remittance category	The description of household remittance categories; 0 = autarky, 1= net receiver, 2 = net giver	(+/ -)
Market distance	The distance from the household to the main livestock market; kilometres	(-)
Town distance	The distance from the household to the main town in the region; kilometres	(-)

Note: Livestock herded are those kept by households but may not necessarily be owning. They can be combination of owned with those belonging to other households or solely belonging to other households.

3.3.4 Estimation Procedure of Ordered Tobit Model

The Extended Regression Model (ERM) framework in STATA was used to fit the data into ordered Tobit model. The estimation was computed in two parts, to account for sequential participation. The first part dealt with the ordered component of the outcome while the second part dealt with the two continuous pieces (sales and purchases). ERM framework allows for estimation with panel data while accounting for complexities like endogeneity and selection biases. It also provides coefficient estimates for endogenous regression (first stage) and the main equation (second stage), using the *xteoprobit* STATA command.

The ordered outcome values in equation 3.9 were replaced with continuous participation and two separate OLS regressions were estimated i.e., one each for sales and the other for purchases to obtain the coefficients for the continuous outcome. This also included the first stage, where duration was instrumented by network coverage as well as the second stage, which is the main equation. The Inverse Mills Ratio (IMR) values for the net buyer and sellers, generated after the ordered Probit estimation, were included in the OLS regression to account for the selectivity problem. This was the second stage of the ordered Tobit regression. It was estimated using *xtivreg* command in STATA. Standard errors were clustered at the household level.

3.3.5 Study Area, Sampling, and Data Sources

The study was conducted in Marsabit County (formerly Marsabit District up to 2010) in northern Kenya as shown in Figure 3.2. The county covers 70,944 square kilometers and is the largest county in Kenya, covering about 12% of the national territory. It borders Samburu county to the south, Isiolo and Wajir to the east, and Turkana county to the west. Ethiopia also borders the county to the north. It is divided into four sub-counties (North Horr, Saku, Moyale, and Laisamis), sub-divided into 20 electoral wards (KNBS, 2019), and 47 sublocations. It has a population of 447,150 people and 77,495 households with an average household size of about 5.8 (KNBS, 2019). The county is home to several pastoral communities, including Borana, Somali, Samburu, Rendile, and Gabra. These communities rely on livestock as their primary livelihood source.

The county receives an annual rainfall of between 200mm and 1000mm with an average precipitation of 254mm, making it one of Kenya's driest counties (Ayugi *et al.*, 2016). The area is also characterized by poor infrastructure, frequent droughts, low market access, and remote settlements. To cope with these harsh conditions, the communities that live in this area mostly practice semi-nomadic pastoralism, where livestock are moved during the dry season in search of pastures and water (McPeak & Little, 2014). The livelihoods of the communities depend on trade in animals to buy other foods and meet their different daily needs (Mahmoud, 2013).

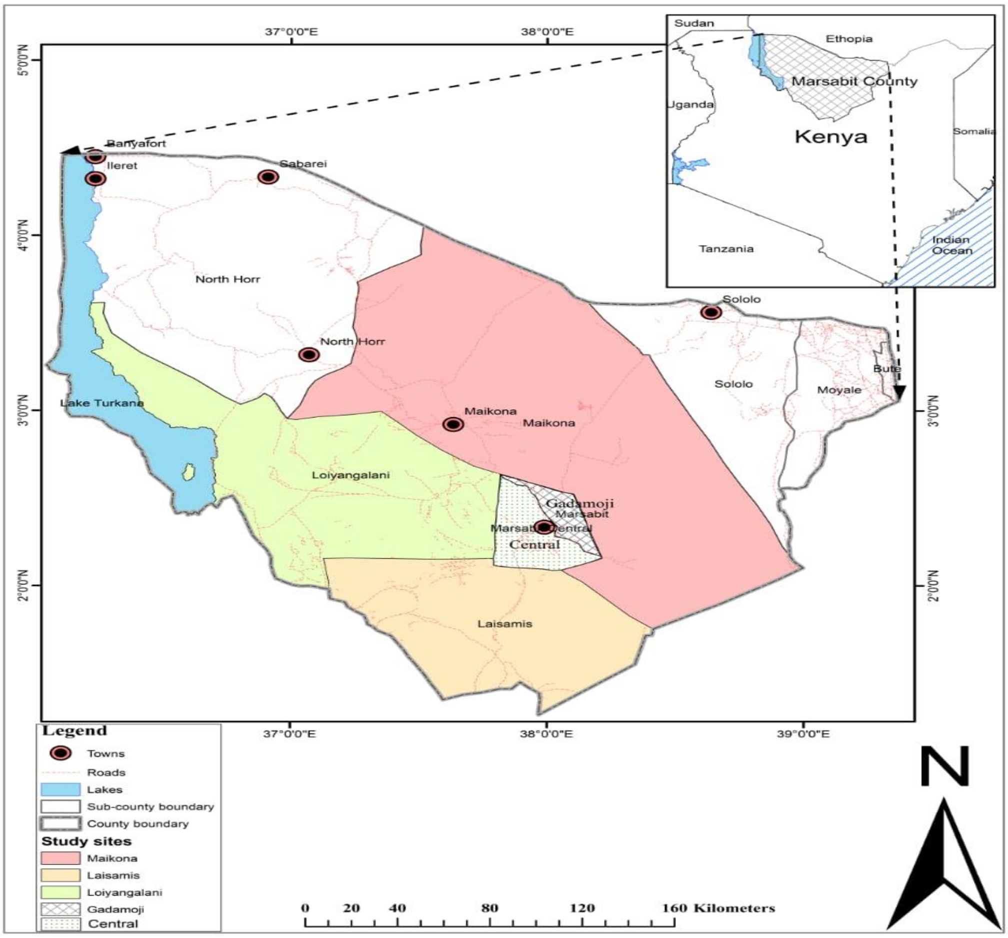


Figure 3.2: Map of Study Sites Using the Current Administrative Boundaries

This study used data collected from pastoralists living in Marsabit County, Kenya. The data was a seven-year (2009-2013, 2015 & 2020) household panel survey collected in 16 out of 47 sublocations, with sample size allocations drawn proportional to the 1999 national household population census. This type and scale of data is not available for other locations in the dryalnds Sublocations were stratified to ensure variation in ethnic background, agroecology, and livestock production systems. Within each sublocation, households were stratified by livestock holdings; low, medium, and high in terms of TLUs. Survey respondents were equally selected from each group. From these steps, a final sample of 924 households was drawn for the interview.

The household head was the main target interviewee, with assistance from the spouse (whenever available). All data were collected using a structured questionnaire by interviewing households within their communities. The households were used as the unit of analysis. The average attrition rate varied per round of survey but with little change in the first six rounds i.e., at 3.4%, and an increase in round seven to 6.1%, which was collected five years after round six. Migration, death and relocation were the main causes of attrition. Table 3.2 provides a more detailed description. Replacement of missing households, strictly using matching TLU class and sublocation was done from survey rounds one to six. No replacements were made in round seven.

There were two periods when the yearly survey rounds were skipped: one year between rounds five and six, and five years between rounds six and seven. The gaps were caused by the unavailability of timely funding to support the surveys. Due to expected social and economic variations, the long span of the missing survey data may have contributed to the higher levels of attrition in the most recent survey round, although generally, the attrition rate was low for a seven-wave panel survey (Ribisl *et al*., 1996). However, the survey questions remained equal across rounds, with only additions, capturing new indicators in round seven. The survey reference period was maintained at 12 months i.e., between two successive survey periods.

Table 3.2: Sample Size and Attrition Levels across all Survey Rounds

Round	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Year	2009	2010	2011	2012	2013	2015	2020
Sample	924	924	924	924	923	919	863
Attrition #	-	37	30	27	13	52	56
Attrition %	-	4	3.2	2.9	1.4	5.6	6.1

Source: Marsabit household survey 2009-2020. # means number.

3.4 Crowdsourcing Platform

3.4.1 Setting up KAZNET Micro-Tasking-Based Crowdsourcing Platform

The KAZNET platform was designed to operate as a micro-tasking platform to be used by pastoralists in rural and remote locations. Its origins are in the demand for better data by the International Livestock Research Institute (ILRI) research team. This demand led to a search for existing viable options, which resulted in a review of the literature and multiple discussions with ICT-for-development experts. The efforts revealed that a few micro-tasking or crowdsourcing platforms were targeting the agricultural sector and, those that were, all focused on crop farming. There were no platforms developed specifically for pastoral systems or even with pastoral systems in mind. Importantly, none of the platforms could work offline, making them effectively useless in most pastoral settings.

While the review did not offer a viable option, it did inform the design and strategy for a scoping mission focused on assessing the potential for micro-tasking in dryland pastoral settings. The scoping mission took place in 2016 with the objectives of assessing the demand for improved data in the dryland pastoral settings and the infrastructure available for ICT-based solutions to meet that demand. It was carried out across different dryland stakeholders including service providers, the private sector, international development organizations, government institutions, and pastoralists. The study showed that there was a high demand among the public and private sectors for a reliable system that could collect and disseminate relevant information at a high-frequency and low cost. Further, smartphone penetration was observed to be high and seemingly offered an opportunity for micro-tasking or citizen science approaches to data collection (Gesare *et al*., 2017).

While the types of information demanded varied across stakeholders in correspondence to their diverse areas of operation, the need for improved livestock market information was identified by multiple stakeholders. A second scoping mission, specifically targeting livestock market information, was undertaken in 2017. The objective of this activity was to develop and pilot the micro-tasking process in remote livestock markets. The results of this second scoping mission and literature on incentive infrastructure used in other micro-tasking platforms reinforced the need for flexibility in the platform.

In 2017, ILRI engaged Ona, a software engineering firm located in Kenya, with a background that includes, among other products, developing Ona Data, a mobile data collection platform based on Open Data Kit (ODK). ODK is an open-source survey software that was developed to function in limited bandwidth environments, thereby meeting the first requirement of functioning offline. The Ona versions of ODK were developed to make it easy for researchers to develop, launch, and update surveys with little or no coding experience. It also met the second requirement of having the flexibility that users could easily adjust to changes in survey tools in near-real-time. Ona developed the entire KAZNET platform, which is completely open source and relies on the same tool-building approaches that all ODK users would be familiar with.

3.4.1.1 Micro-Tasking Platform Process

The KAZNET platform consists of two main pieces of infrastructure, a web application, and a mobile application. The web application is used by the administrators of the platform to design and manage tasks, approve, or reject submitted tasks, and access the submitted data figure 3.3 demonstrates the sequence of actions between an identified demand for data and the delivery of that data.

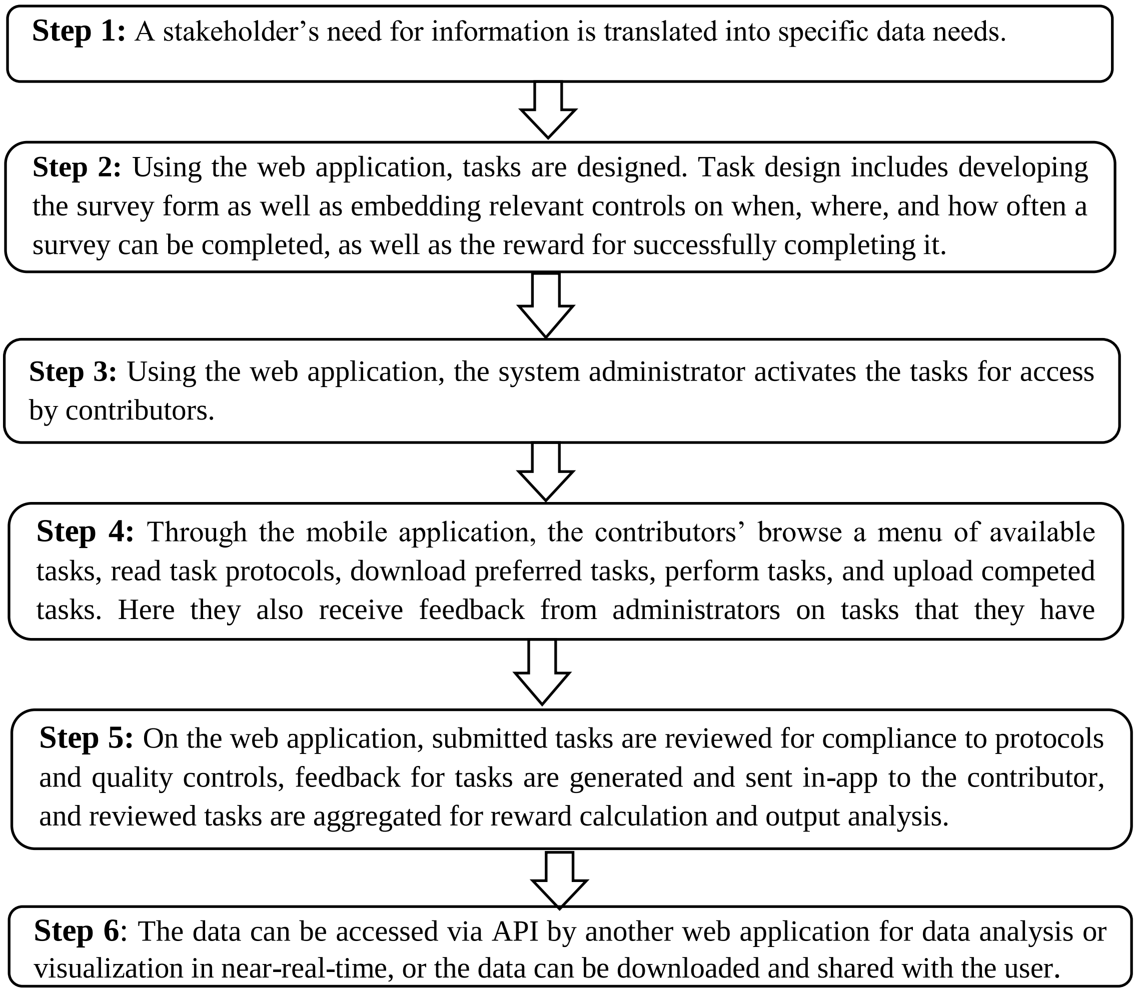


Figure 3.3: Design Flow of the KAZNET Platform Activities.

To design tasks involves developing sets of instructions and activities, such as a survey to be collected from a shop or a market, and a set of parameters related to that survey. The parameters include (1) where the task can be completed i.e., the geofence, (2) when tasks can be completed i.e., the temporal gate, (3) the frequency that the task can be completed, and (4) the reward for accepted task completion. The mobile application provides contributors with a menu of available tasks, with descriptions of parameters and filtering options for geofences and temporal gates. It allows the registered contributors to download tasks for completion offline, perform tasks, submit tasks, and receive feedback on the quality of their submissions (e.g., the reason that a task was rejected). Following the micro-tasking logic, the KAZNET system has been designed to be flexible in both the backend and the front end, while considering limitations posed by the context; a detailed description of the two applications is provided in the next sub-sections.

3.4.1.2 The Web Platform

The KAZNET web application is custom-built by Ona to provide an interface for developing, deploying, managing, and approving tasks. In the current deployment, tasks are defined as an ODK form with a related set of parameters that define protocols. Task development then includes two steps i.e., authoring forms and defining parameters. In our case, forms are authored using the Ona Data platform, but other platforms (e.g., Kobo Collect, Survey CTO, ODK Cloud) could feasibly be linked to the KAZET web application. Importantly, all the standard features of ODK forms are available for form development, including question types, time stamps, geo-stamps, photo capture, video/audio playback, skip logic/branching, as well as application features such as remote updating forms. The task is then defined within the KAZNET web application as the ODK form, and the set of parameters is defined there as shown in Figure 3.4.

Contributors are registered, allocated login credentials, and progressively categorized by performance and experience. Those with consistently high performance (experts) could access some tasks that are deemed too challenging or sensitive for unproven beginners. Rewards are set to reflect the data needs and the complexity of the tasks. Tasks requiring more effort are priced higher than those that require less effort. The rewards could be dynamic to respond to incoming data, for example, to reduce rewards for tasks as data goals are met.

.

The **status** allows the administrator to activate or deactivate a task.

The **description** is a simple set of instructions for the contributor.

The **reward** is the amount that contributors are paid for submitted and accepted tasks.

The **active dates** are the periods between which the task is available for download or completion.

The **location** for the task is defined either by uploading shape files of the geofence or as the regions within a specified circumference of a set of uploaded points.

The **timing rules** define which day(s) and during which periods of the day the contributor is allowed to complete the task.

The **client** defines the target entity or institution that needed the data collected.

The **Submission limit** defines the maximum number of submissions expected from a contributor.

The **contributor level** defines the level of experience needed by the contributor to have access to the task.

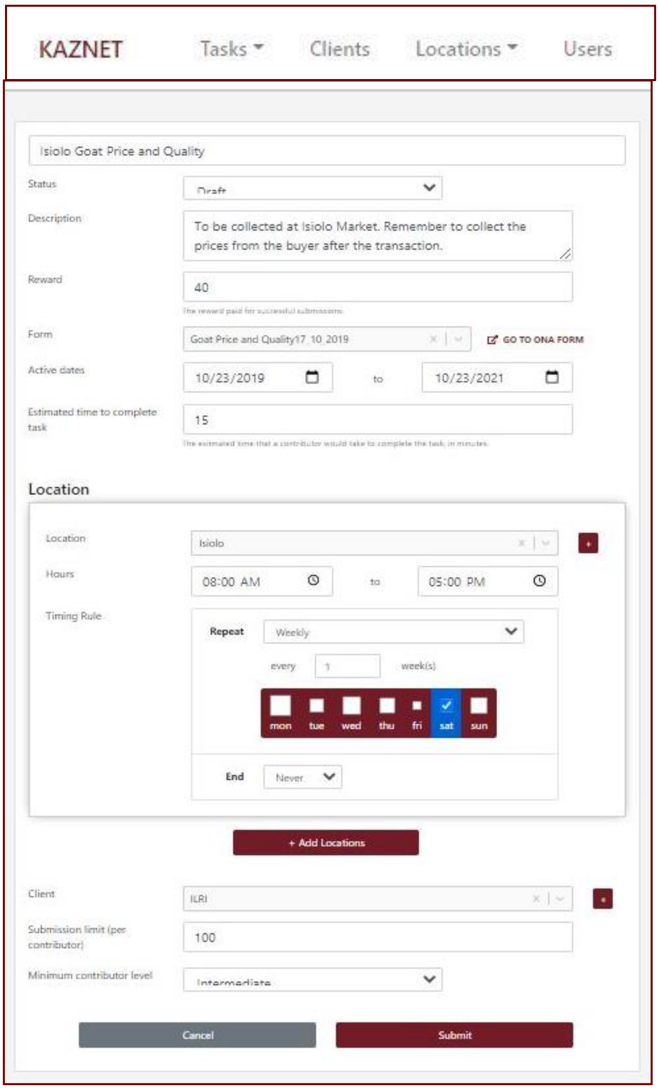


Figure 3.4: The KAZNET Web Application Used to Define Task Parameters.

All submitted tasks are managed using the Ona Data web application. Here, administrators can individually accept or reject submitted tasks in bulk. Most rejections were either automatic, because they violated a parameter, or because the photo does not meet the requirements.

Figure 3.5 provides a screenshot of a task being validated by a system administrator. This includes the photo, the location, the time the task was completed, and the domain of prices. These details help in checking data quality. Further, this submission could be cross validated using other submissions in the same market on the same day. Rejected submissions are accompanied by justifications whereas accepted submissions are coupled with applaud statements. The review outcomes are accessible to the contributors at the mobile application interface. They are also used as inputs for ranking contributors. Data aggregation, generation of information outputs, reward calculations, and retrieval are completed after review.

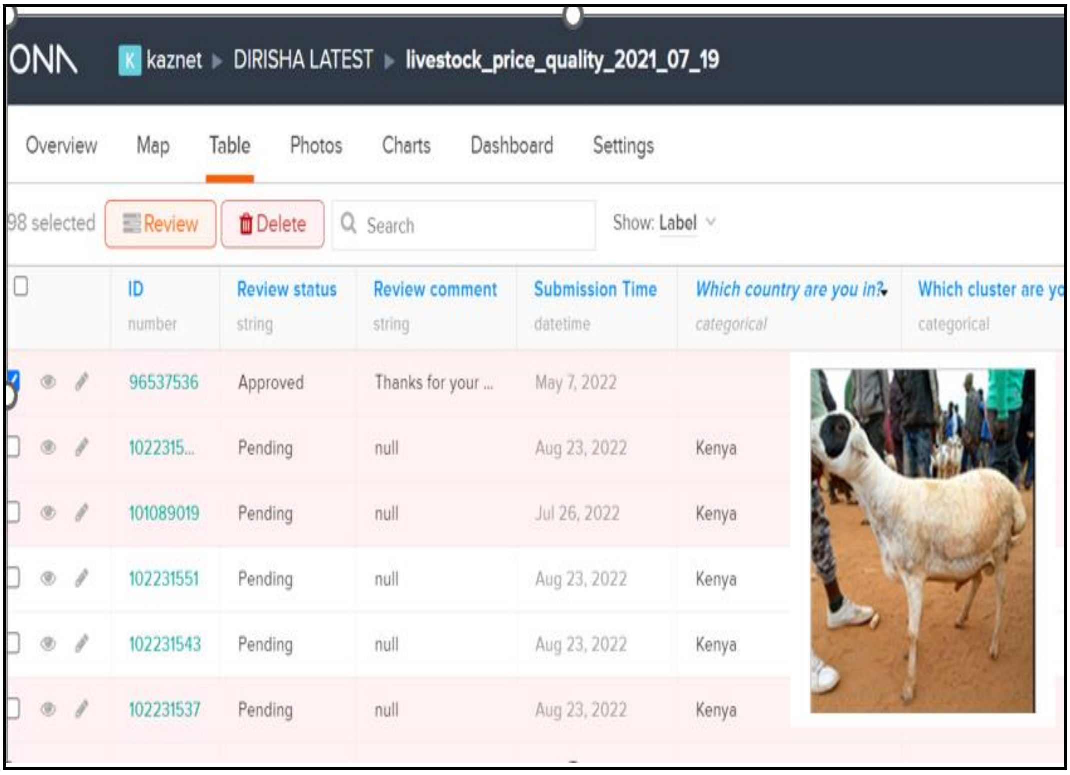


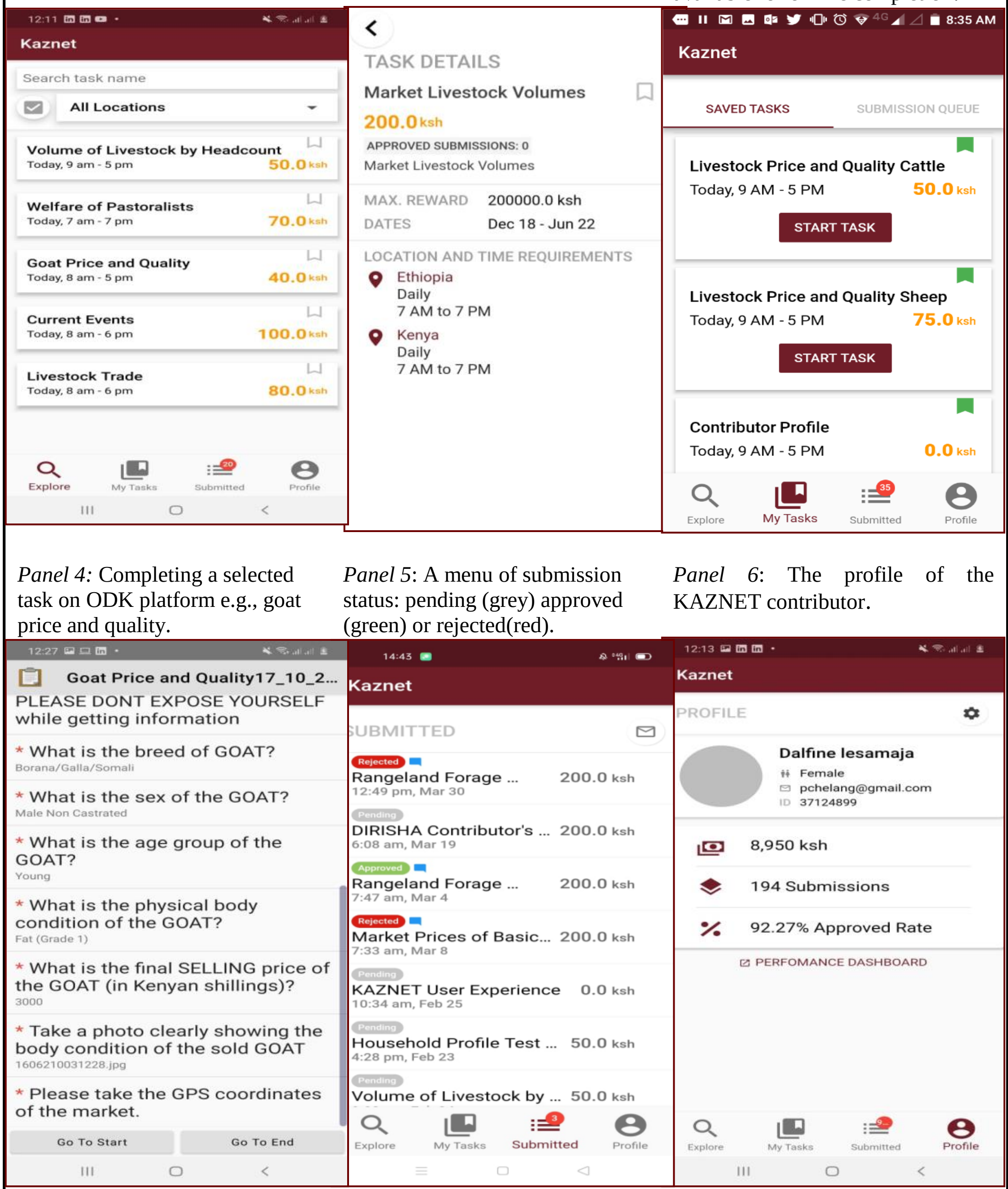
Figure 3.5: Using KAZNET's Web Application to Validate a Submitted Task.

3.4.1.3 The Mobile Platform

The KAZNET mobile platform is an integration of a tasking wrapper on top of the ODK mobile client software. The wrapper performs two main functions. The first is to create a tasking user interface, that allows contributors to browse available tasks and related protocols (e.g., locational requirements, rewards for completion), download tasks for completion offline, manage tasks, receive feedback on tasks, and track profile-level attributes. The second is to check for conformity to task parameters, for example, that the device is within the livestock market before the contributor can complete the livestock market task.

Once the contributor selects a task that she would like to complete, the task itself opens as an ODK form. This allows KAZNET to leverage the years of investment by ODK in form development and use for mobile device owners in different locations. The forms are then completed per the instructions. As mentioned earlier, ODK forms have a wide variety of functions, including taking geo-point, responding to a diverse set of question types, taking photos, and playing audio or video files. Completed tasks are saved on the device for submission when the mobile device has connectivity.

Figure 3.6 provides a series of screenshots of the front-end interface that a contributor would see while using the mobile application. In Panel 1, a contributor online uses *Explore* to browse available tasks, filter by location, and choose the ones to perform. Panel 2 provides an example



Panel 1: Menu of available tasks based on choice of location.

Panel 2: Details of a task.

Panel 3: Downloaded tasks available for offline completion.

Panel 4: Completing a selected task on ODK platform e.g., goat price and quality.

Panel 5: A menu of submission status: pending (grey) approved (green) or rejected(red).

Panel 6: The profile of the KAZNET contributor.

Figure 3.6: The KAZNET Platform Front End Schema

of what the contributor might see when selecting a task for more information. Here, the administrators can provide details on the reward, location, and frequency details of the task, as well as any other instructions. Contributors then download tasks that they would like to save on their devices for completion later. Panel 3 shows a contributor in the *My Tasks* tab, which shows that she has three tasks available for completion, either on- or offline. Note that a single task can be completed as many times as the parameters allow. So, for example, once downloaded, the contributor can complete the *Livestock Price and Quality* task multiple times in each market, each week.

To complete a task, the contributor selects the task, and it is launched in the ODK Collect mobile application (Panel 4). Once completed, tasks are stored on the device until they are submitted, which takes place in the background when the device has connectivity. The *Submitted* tab shows the status of each completed task (Panel 5). Submitted tasks are pending, until they have been approved or rejected by an administrator, which can be done individually, task-by-task, or using spot checks and bulk acceptance/rejection or using an automated process. When the administrator provides a comment (whether bulk or individual) on a task, a small blue comment icon is indicated on the task in the *Submitted* tab, and the contributor can view that comment by selecting the task. The *Profile* tab provides a summary of the contributor's performance (Panel 6).

Both the KAZNET wrapper and ODK Collect are available on the Google Play Store for download. Login credentials, which include a username and a password are provided by the system administrator for logging in to KAZNET, which will then provide credentials to the ODK client.

3.4.2 Theoretical Perspective of Incentives and Participation

The study focused on whether market price information feedback could complement piece-rate monetary incentives to increase participation in crowdsourcing for livestock market information. Using the agency theory, while assuming the actions of the principal (the entity engaging) and the agent (contributor) can be observed, measured, and compensated, the relationship can be formulated mathematically as follows.

$$y = e + \varepsilon \qquad 3.10$$

Where y, represents the output produced by the agent using effort e plus conditions around the agent that influence output but are beyond the control of the agent, denoted by ε. In the context of this study, the output is the number of tasks performed by the contributors while the effort corresponds to what it takes an agent to perform a task e.g., the time taken to the market, effort used to engage stakeholders, skill to navigate the application, etc. The unforeseen conditions, which for simplicity of the mathematical model were assumed to be $E(\varepsilon)=0$, may include the application breaking, failed interviews, mobile phone brand functionality limitations, etc.

The agent requires a contract that would shape his actions to achieve the desired level of output. Output produced is compensated by the principal in the form of wages, denoted by w, which is a linear function of output. If the outputs are objectively verifiable, each unit is paid a piece rate, denoted r. The compensation is deemed to be the total wage over a specified period. The rate in the context of this study is the reward attached to the completed task, while the wage corresponds to the total pay for completed tasks. The wage function is assumed to be linear, as follows.

$$w = r.y \qquad 3.11$$

The contract between the principal and agent leads to benefits (payoffs) that are defined differently by both. The payoffs for the agent and the principal are expressed in terms of utility and profits respectively. For generality and simplicity, both are assumed to be risk-neutral, and thus a favorable contract would be one that would consequently maximize utility and profits i.e.,

$$\mu = w - c(e) \qquad 3.12$$

where μ is the utility received, $c(e)$ is the cost of effort incurred by the agent to perform a task. A risk-neutral agent wants to allocate minimum effort that maximizes the wage (w) received for any given task. On the other hand, the principal's objective function to maximize profit is denoted as follows: -

$$\pi = y - w \qquad 3.13$$

where π, is the profit and is the difference between the value of output (y) and the wages (w) paid to the agent. A contract that minimizes the unit cost of output, without reducing the effort of the agent is favorable to the principal. Therefore, the expected profit (payoff) of the principal, in the long run, is, $E(\pi)= E(y\text{-}w)$, which is a random variable dependent on the performance of the agent. In the context of this study, the intention was to establish whether price information feedback framed in the form of dissemination could complement low piece rate monetary compensation to trigger high agents' levels of effort and resultant utility to perform tasks through the KAZNET platform.

3.4.2 Econometric Specification of Participation in Crowdsourcing

Contributor participation was the outcome variable targeted in this objective. It is a variable observed using two other outcomes that are assumed to be a result of two different data general processes: the decision to perform, which is a latent variable, and the number of completed tasks. Allocation of time and effort to perform a task means that the utility of performing that task is higher than for other non-crowdsourcing activities. A random utility function was used to express the qualitative response as follows.

$$U_0=v_0+e_0,\ \ U_1=v_1+e_1 \qquad 3.14$$

$$P(y=1) =P(U_1> U_0) \qquad 3.15$$

Where U_1 and U_0 are the resultant utilities of contributors choosing to perform or not perform a task respectively. Therefore, the probability that a contributor performs a task is the probability that the utility of performing is greater than that of not performing. In the next stage of the performance matrix, each contributor will maximize the effort to meet the required number of submissions to receive higher compensation and resultant high utility associated with performing the task i.e., $y_{it}=1$, otherwise $y_{it}=0$.

This analogy was used to model the decision to perform a task, and for those who chose to perform, then decide how many to perform. So, let y^*_{it} and Z^*_{it} be latent variables describing the decision to perform tasks and the number of tasks to perform per period, respectively. If $y^*_{it} > 0$ then the submissions are observed at the backend and thus $y_{it} = y^*_{it}$, and if $y^*_{it} \leq 0$, then no submissions are observed, and thus $y_{it}=0$. The observed outcome generation process is also a function of time-variant and time-invariant individual and institutional characteristics and an error term for each step.

$$y^*_{it} = M_i\alpha + X_{it}\beta + \mu_{it} \quad 3.16$$

$$Z^*_{it} = C_i\alpha + W_{it}\gamma + \varepsilon_{it} \quad 3.17$$

If it was assumed that the two-outcome generation process was determined by completely distinct factors, then a count data model that allows for censoring responses like double huddle by Cragg (1971) would be ideal. This will treat the two-step process as determined by distinct explanatory variables. Contrary, limited dependent variable models like the Tobit model by Tobin (1958) allow for the two data generation process to be analyzed using the same variables but jointly using a binomial Probit model and an OLS regression model.

3.4.3 Experimental Design and Data Variables

The micro-tasking experiment was conducted for 19 weeks, from November 2019 to March 2020. The experiment entailed testing the difference in participation levels between two groups of contributors subjected to two incentive regimes as shown in Figure 3.7. The first group (control) was incentivized using piece (task) rate monetary rewards over the entire experiment period. The second group (treatment) was treated in sequence. First, it was incentivized using an identical piece rate regime as the control group (weeks 1- 6). Secondly, they were given.

<table>
<tr><td>Intervention</td><td colspan="6">Pre-treatment period</td><td colspan="6">Treatment period one</td><td colspan="7">Treatment period two</td></tr>
<tr><td>Timelines (weeks)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td></tr>
<tr><td rowspan="3">Nature of treatments given to the two experimental groups at a given period</td><td colspan="19">Monetary incentive (Both Control and Treated group)</td></tr>
<tr><td colspan="6"></td><td colspan="13">Market price information incentive (Treated group ONLY)</td></tr>
<tr><td colspan="12"></td><td colspan="7">Price information script (Treated group ONLY)</td></tr>
</table>

Figure 3.7: Micro Tasking Participation Timeline and Allocation of Treatments between Groups.

Access to timely livestock market price information as treatment one (weeks 7-12) alongside monetary incentives. Finally, they were given access to an informational script as treatment two (weeks 13-19), together with the two earlier incentives. Using the same setup, two types of incentive effects on participation (direct and spillover) were tested. The effect of the incentives on participation levels of market price tasks was regarded as a direct effect. The market price task was not only the main link to market information asymmetry focused on the study but also the incentives were directly targeted on its increased submissions. In addition, treatment one and two incentives were directly targeted at this task. The spillover effects of the incentives were tested through the levels of consistency in the submission of the daily welfare task. It was referred to as “spillover” since the incentive regimes tested were not directly targeting its submission consistency. Rather, the effect was through motivation induced by livestock price tasks via the strong correlation between pastoralist households’ welfare and livestock markets.

Monetary rewards were the primary incentive, where each task had a price pegged to it, hence, the piece rate reward regime. The price range for each completed task was KES 30 to 50 (0.3-0.5 USD). The differences in prices were based on the variation in efforts necessary to complete a particular task. Each day, contributors make the personal choice on whether to perform tasks or not; they choose the type and number of tasks to perform. The total reward earned, assuming the contributor performed all required tasks within the weekly cycles, was cumulatively calculated to correspond to the average wage payment for closely related activity in the region. In addition to the task-based monetary incentive, a flat rate of KES 100 (approx. 1 USD) was paid weekly to each active contributor as compensation for data bundles necessary to complete the micro-tasking activity.

In the first six weeks of the experiment (pre-treat), the contributors in the two groups were incentivized using only monetary incentives pegged to each active task. The intention was to ensure that the contributors were well acquainted with using the KAZNET platform and the scheduling of the tasks. It also provided the necessary baseline trend in contributor participation. The total weekly pay was calculated based on contributors’ submissions and paid through an electronic money transfer platform called M-Pesa.

Livestock market price information was provided to the treated group in addition to the monetary incentive. It was generated from aggregated market price data submitted by contributors from different markets. They were presented in simplified tables of weekly price summaries of all animal types traded in each of the sampled markets. It was assumed that contributors could easily observe and compare the price differences between animal types and grades sold in the sampled markets. The price information tables were generated and shared each time additional market information was submitted from an active market. The treatment began in week seven and lasted through the end of the experiment. Table 3.3. provides an example of the price information tables shared.

Table 3.3: Market Price Information Summary of Goats Traded in Some Sampled Markets

Market Name	Market Date	Goat Age group	Average price	Min price	Max Price
Isiolo	6/3/2020	Mature	5,886	2,000	9,000
		Young	3,263	2,500	3,800
Archers Post	7/3/2020	Mature	4,841	2,250	8,500
		Young	2,000	2,000	2,000
Merille	10/3/2020	Mature	4,467	2,000	10,000
		Young	2,300	1,700	3,000

The three markets in Table 3.3 Isiolo, Archers Post, and Merille are located along the main livestock corridor in a livestock catchment reaching from Moyale at the Ethiopian border to Nairobi, with 50-150 kilometers between each market. Isiolo market is in a more urban setting than Archers Post and Merille markets, respectively. The price information provided was intended to fill the market information asymmetry gap prevalent in the region.

In addition to the monetary and market price information incentives, the contributors in the treated group were given an information script shown in Figure 3.8. The script was aimed at linking, in the minds of the contributors, the task submission levels and the quality of the market price information that they were receiving. It also highlighted how access to price information could improve livestock marketing decisions. It was shared with the treated group together with market information beginning in week 13 up to the end of the experiment.

Two subsamples were created from the ten study markets, each constituting contributors from the five markets. The five markets in each subsample represented a trading catchment area in the three sampled counties. Each of the two livestock catchment areas was allocated to one of the treatment groups. Randomization at the individual level or market level risked a high degree

Thanks for your continued participation in KAZNET. We use the valuable data you provide to generate information, such as the ones we always send to you about livestock market prices. The main intention is to consistently provide accurate information that can improve your knowledge and decision making in livestock marketing. This activity of sharing information back to you from your market and other markets cannot be done without your support—thank you. You have all noticed that we can only pay money for tasks up to a certain limit due to budgetary constraint. That's the nature of budgets. However, we encourage you to submit more than the payable limits because more tasks increase the accuracy of the information shared back to you. We also believe that you often share the information with your relatives and friends so that they can improve their livestock marketing decisions. Thank you.

Figure 3.8: Script Elaborating on the Link between Submissions and Information Feedback

of spillover (and even confusion or jealousy) because contributors within catchment areas were often colleagues that communicated frequently, and the nature of the informational treatment made it easy to share digitally. Indeed, the informational treatments were provided through a WhatsApp group that comprised all the contributors in one of the catchment areas.

The variables used in the model are shown in Table 3.4. The contributors' average weekly submissions for livestock prices and quality tasks, and the sum of daily submissions for household welfare tasks, were the outcome variables of interest that measured participation. Sequential treatments were provided as described in Figure 3.7. Market connectivity is a dummy variable that signifies the closeness of markets to the tarmac road, i.e., a market located less than five kilometers from the tarmac road was categorized as highly connected while those further were in the lowly connected category. Contributors were more likely to have better mobile support services and a higher propensity to use digital systems if they were closer to the tarmac. Similarly, contributors' distance to the market (in kilometers) was expected to negatively influence participation. This was despite most contributors being drawn from communities close to the sampled markets as there was still some degree of heterogeneity in the actual distance to the market.

The contributors' social group membership status dummy was used with positive expectations for members. Group members are more likely to be active information seekers than non-

Table 3.4: List of Variables Considered in the Estimation of Contributor Participation

Variable	Variable descriptions, values, and value labels	Hypothesised effect
Prices submissions (Outcome variable)	Average weekly livestock prices submissions; 1= Week 1- 6 (before treatment), 2= Week 7-12 (treatment one), 3 =Week 13-19 (treatment two	
Welfare submissions (Outcome variable)	The weekly sum of household welfare submissions; 1= Week 1- 6 (before treatment), 2= Week 7-12 (treatment one), 3 =Week 13-19 (treatment two	
Piece-rate monetary incentive	The amount of money paid for any individual task completed by the contributors (range: KES 30-50)	(+)
Price information	The information package containing prices of livestock in relevant market pairs; 1 = yes, 0 = no	(+)
Price information script	The link between the task submission and the quality of market information; 1 = yes, 0 = no	(+)
Market connectivity	Closeness of assigned market to tarmac road; 1 = near tarmac, 0=far from tarmac	(+)
Group member status	Group membership status of the contributor; 1=yes, 0 = no	(+)
Gender	Gender of the contributor; 1 = male, 0 = female	(+,-)
Education level	Education level of the contributor; 1=high, 0= low	(+,-)
Distance to market	Distance to the assigned markets (Kilometres)	(-)
CAPI experience	Experience of the contributor in computer-assisted personnel interviews; 1 = yes, 0 = no	(+)
Age	Age of the contributor (Years)	(-)
Livestock owned	Number of livestock owned by the contributor -TLUs	(+)
Main occupation	Main occupation of the contributor- categorical, 1 = Pastoralist, 2 = Casual labour, 3 = Government employee, 4 = Livestock trader 5 = Livestock Market agent, 6 = Shop keeper	(+, -)

members. The age of contributors was measured in years. Both positive and negative effects on participation were expected. Being young would favor ease of use of digital systems. Similarly, older contributors would be more responsive to the process that generates valuable information because they are more likely to have participated in livestock production and marketing, unlike younger groups.

Livestock ownership, measured in TLUs, was expected to influence participation as the units increase. This assumed that owners of large herds were more likely to be concerned with livestock marketing issues than those with fewer or without livestock. This group is sometimes characterized as “dropping out of pastoralism” (McPeak *et al*., 2011). The main occupation of the contributors, which was represented in six categories, with pastoralism as the base category, was expected to influence participation in varied ways, as effort allocation would vary depending on the circumstances affecting the contributor at a given task collection instance. Education dummy categorized those with primary level and below as “low level” and “high- level” for those with other levels above. Variation in participation was expected between the two levels as those with higher education level were more likely to be responsive to micro-tasking activity because of more exposure to online job markets and a higher propensity to seek more market information. Conversely, they would also be less keen on such engagements as their return to marginal effort on other activities could be higher.

3.4.4 Estimation Procedure of Contributor Participation Response to Incentives

A Difference in Difference identification framework was used to estimate the Average Treatment Effects (ATE) on the treated group. DID uses aggregate data from both control and treated groups to estimate the effects of the treatments (Angrist & Pischke, 2009). Identification through DID assumes that, in the absence of treatment, both groups would follow the same trend and level, with observed drifts linked to time and group fixed effects (Wooldridge, 2010). Treatments introduced induce deviations from pre-treatment trends (Angrist & Pischke, 2009). The general DID regression model allowing different timings of the treatments for different units (Goodman, 2021) is represented as follows.

$$y_{it} = \gamma_i + \vartheta_t + \delta D_{it} + \varepsilon_{it} \qquad 3.18$$

where y denotes the outcome variable (submissions), i is the unit (contributor), t is the period, γ_i is the unit fixed effects, ϑ_t is the time fixed effects, $D_{it}$is the unit-time indicator of the treatment, δ represents the coefficient to be estimated in each 2×2 interaction identified from the setup.

In the context of this study, the participation levels of two groups of contributors before treatment and after the provision of the two phases of market price information treatments provide a mechanism for estimating the treatment effects on the treated group (Angrist & Pischke, 2009). The DID strategy was the most plausible way to deal with possible differences in participation between the treatment and control regions and it conformed well with the experimental design employed in this study. This study is a unique two-group/three-period DID, with the control group remaining fixed (as control) for the entire period while the treatment group was treated twice, i.e., in week 6 and week 13. The second treatment in week 13 was a reinforcement of the first treatment. The interaction of period and group dummies following the DID framework represented the key independent variables whose coefficients were estimated.

Participation was the outcome variable measured by the weekly individual tasks' submissions. The participation outcome across weeks could take a nontrivial zero value when no submission was made, and a range of positive values if a submission was made. The data generation process for the outcome variable allowed estimation using specifications in the limited dependence variables category models. If both values (zeros and positives) were assumed to be generated from a joint decision process, then a Tobit model (Tobin, 1958), would fit the data well. The Tobit model generates nonnegative predicted values of the outcome variable and sensible partial effects over a range of explanatory variables (Wooldridge, 2012).

The model used the underlying latent variable (y^*) to express the observed outcome (y) as follows.

$$y^* = \beta_0 + x\beta + \mu \qquad 3.19$$

$$y = Max(0, y^*). \qquad 3.20$$

The observed variable, y, equals y^* when $y^* \geq 0$, but y=0 when $y^* < 0$. The β is parameter(s) to be estimated given a list of independent variables. From this specification setup, two expectations are estimated: $E(y|y > 0, x)$, which is the conditional expectation i.e., the truncated data, and $E(y|x)$, which equals estimation using censored data with zeros included.

A panel Tobit model was used for estimation, given that the data was a weekly panel of contributors' submissions. The model assumes random individual and time effects in the estimation of coefficients for both treatment and other observed time-variant or invariant independent variables. Using the Tobit model in a DID framework for the outcome and covariates respectively, the following empirical equation specification was estimated.

$$Y_{it} = \beta_0 + \beta_1 TR_{it} + \sum_{p=1}^{3} \beta_2^p TRP_p + \sum_{p=1}^{3} \beta_3^p (TR_i * TRP_p) + \beta_4 Z_{it} + \gamma_i + \vartheta_t + \varepsilon_{it} \qquad 3.21$$

Where, Y_{it} is the outcome variable of an individual over time (weeks), β_0 is the average submission before treatment, TR is treatment group (control =0, treat = 1),

TRP_p is the treatment period $\{p = 1,2,3\}$, Z_i is the contributor characteristics, γ_i and ϑ_t is the contributor and time fixed effects respectively.

Estimates for a non-conditional Tobit regression were explored for robustness checks. In addition, estimations were made from alternative specifications using OLS with data aggregated by week and another by the treatment phases. Poisson regression was explored because the data generation process could also be viewed as a form of count data. The results are presented in Appendix IC for further robustness checks.

3.4.5 Hypotheses Testing for Feedback Provision

Selective feedback provision to contributors created two groups; one homogenous group receiving a consistent supply of information deemed to be useful on their economic activities to signal the importance of the KAZNET platform and another that did not receive such feedback. The two comparison groups whose difference in outcome was measured in terms of performance were hypothesized to be the same. From data collected through the experimental design, a comparison of means of submissions between the treated and untreated group (control group) was done. Based on the distribution plots and the kernel density curves, parametric tests were used, and thus a p-value set at 0.1 was the cut point of decision-making.

3.4.6 Study Area, Design, and Data Sources

The study was conducted in three purposively selected counties in northern Kenya: Marsabit, Samburu, and Isiolo. Ten markets, comprised of eight intermediate markets (Isiolo, Oldonyiro, Lekuru, Maralal, Merille, Lolkuniani, Marsabit, and Moyale) and two feeder markets (Korr and Archers-Post) in the three counties were selected as shown in Figure 3.9. Feeder markets are the smallest and domiciled closer to production catchments than the Intermediate market. These markets are geographically dispersed to represent a wide catchment area. Most of the markets operate on predetermined weekly cycles, with a few in major towns active daily but with a single larger market day each week. The supply of livestock during market days is usually in the hundreds but can be much larger or smaller in some cases. On each market day, trading mostly begins in the early morning and ends in the afternoon i.e., from 8 am to 2 pm. Livestock supply and the peak of trading activity vary across markets and market days.

A pool of contributors was purposively selected from communities living close to the livestock markets, using a network of local livestock market managers and administrators. These were residents with smartphones, who were knowledgeable and interested in livestock production and marketing. Through this process, a sample of seven contributors was identified from each of the ten sampled livestock markets. The contributors were provided access to tasks seeking market data highly demanded by pastoralists and other stakeholders (Gesare *et al.*, 2017). The tasks were developed and launched on the KAZNET micro-tasking platform. The selected contributors were trained in their locality on how to use the KAZNET application. A menu of the available tasks was uniformly accessible to the contributors on each market day. Additional tasks on contributor demographic information, the welfare of households living close to the sampled markets, and prices of basic consumption commodities were also included.

Market data on livestock volumes and prices were collected. Livestock volumes were obtained by counting the total number of animals present in their local markets, with zero indicated for animal types missing in the market. Due to the limited changes of volumes in a market day, one submission per contributor per market day for this task was sufficient. Any variation across market hours was assumed to be evened out by averaging across contributors collecting data at different market peak hours. The livestock price task was designed to capture prices of available animal types following standardized livestock quality dimensions indicated by the Kenya Bureau of Standards (KBS). To cover the quality heterogeneity within livestock type

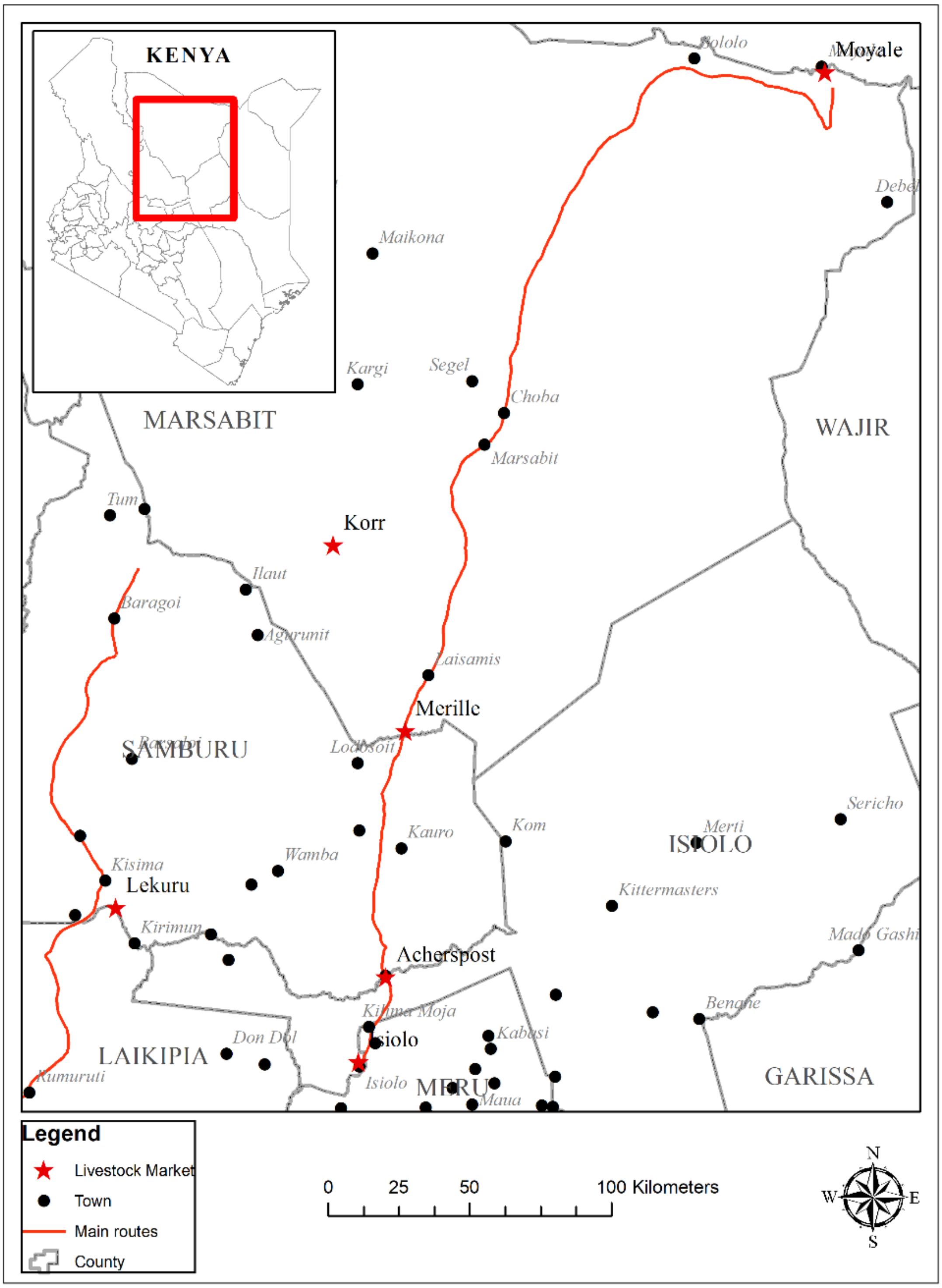


Figure 3.9: Geographical Placement of Sampled Markets in the Sampled Counties

traded, and to have representative data, contributors were expected to perform multiple submissions per animal type present. Hence, the quality of the price data was anchored on the number of tasks performed and submitted by the contributors.

Household welfare indicators were collected through tasks administered to pastoralists living in communities close to the markets. The task was active from Monday to Saturday every week. Contributors randomly sampled households within their communities for monitoring over the experiment period. Contributors could collect daily tasks on dynamic indicators that are otherwise difficult to obtain using conventional data collection protocols. There were no restrictions on the time of day when data should be collected. Like other tasks, GPS and time stamps were all embedded as quality control mechanisms. For this task, one submission per day was expected, and thus a maximum of six submissions per week, Sunday excluded.

The submissions for livestock market prices and household welfare tasks were used to evaluate contributor participation levels. High task submission rates on prices of livestock were necessary for the success of the micro-tasking platform. In this context, more submissions meant that the submitted data was from a larger sample, and thus closer to the true livestock markets' trading experience in each market and the entire region. The bulk of data collection efforts targeting these indicators has failed in providing reliable and consistent data over a long period (Stuth *et al.*, 2006; Tollens, 2006). It, therefore, required that contributors engaged be sufficiently motivated to participate in the data collection activity. Participation rates were assumed to be a function of the contributor's motivation level as influenced by incentives provided for each task (Ghezzi *et al.,* 2018; Jiang *et al.,* 2021). Hence, high submission levels for the market price tasks were an indicator of sufficiently motivated contributors and vice versa. Participation that led to daily submission, without skipping some days, was also expected on the household welfare task.

CHAPTER FOUR

RESULTS: PASTORAL LIVESTOCK MARKETS INTERGRATION

4.1 Introduction

This chapter shows the results and discussions addressing objective one of this study. It focuses on the state of spatial market integration in the pastoral markets. It begins with a description of the price trends and the summary statistics for goats' price levels for all sampled markets. It also shows and explains the results of the relevant tests conducted: stationarity, estimation of the optimal time (weeks) lags, cointegration, and the results of VECM regression. The VECM results and discussions are focused on the short and long-run causal relationships of the market prices in the region.

4.2 Weekly Market Price Trends

Figure 4.1 and Figure 4.2 show the weekly price trends of the six sampled markets. As earlier indicated, the goat price data was used for analysis because of its completeness in all the sampled markets. The evolution of goat prices over the 11 months showed a predominant pattern of low variability among price series. Seasonality of price trends, mainly caused by pastoralists' market behaviour in responses to dry and wet seasons, was limited. Figure 4.1 shows that it is only in Moyale, which is a border market between Kenya and Ethiopia that showed an increase in prices in the second half of the long rain season (May to June). The price increase was likely occasioned by the cross-border price dynamics. This is also supported by the trend exhibited by its fitted values shown in Figure 4.2.. The fitted values for all other markets are a horizontal movement with muted fluctuations, thus suggesting the presence of stationarity. On aggregate, the minimal variation and absence of glaring seasonality observed in the price trends could be attributed to the general normal forage conditions experienced in most pastoral rangelands in 2019 and 2020.

Figure 4.2 also shows the response of weekly mean market price to other non-market shocks during the period. As such, there are notable price shocks in a few markets (Merille, Lekuru, and Acherspost) in the third week of April 2020 (the vertical line in the x-axis). This corresponds to the period in which the Kenyan government imposed COVID-19 movement restrictions. Prices increased in Merille for two weeks consecutively after the restriction, dropped on the third week, and stabilized thereafter.

In Lekuru and Acherspost markets, an increase in price for two weeks was observed after the restrictions. The restrictions affected formal market access and trade temporarily shifted to informal settings (Graham *et al*., 2021; Chelanga *et al.*, 2020). However, the commonality of some price responses to the non-market shocks in the markets suggests the existence of integration.

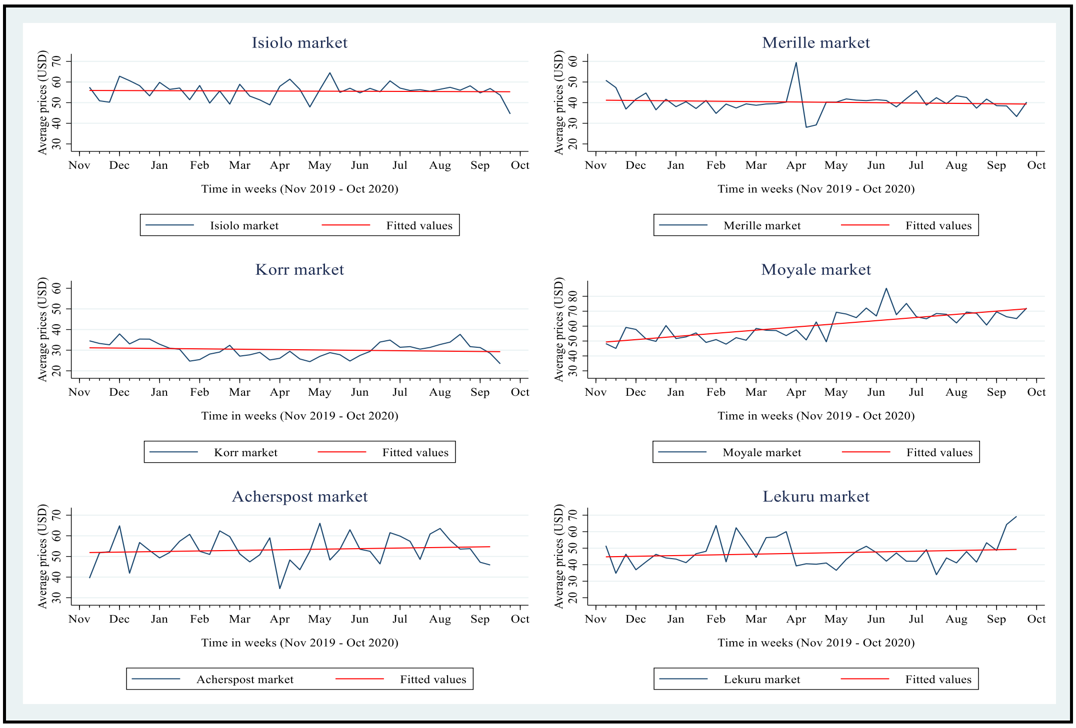


Figure 4.1: Individual Market Price Trends for Goats Traded in Six Selected Markets.

Prices in Korr and Merille markets remained low over the entire period of the study. This could be attributed to being domiciled closer to pastoralist production catchments. Prices in other markets were at the same levels for most of the period. It is only in the Moyale market that began trading at relatively high and increasing prices in the later weeks.

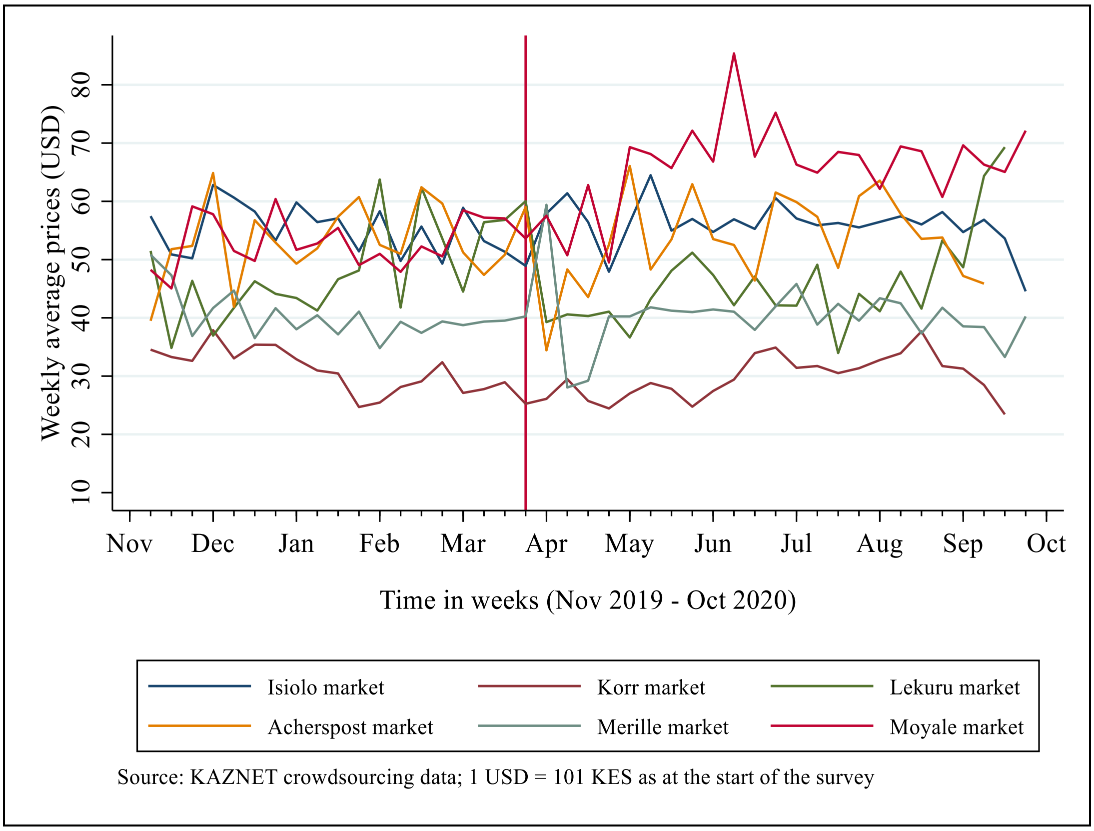


Figure 4.2: Market Price Trends in the Six Sampled Markets.

Table 4.1 shows the pooled price summary statistics of the six sampled markets. The mean prices decrease as markets get closer to production catchments. This suggests a clear trade flow of goats from low-price markets to higher-price markets. Consistent with trends depicted in Figure 4.2, Table 4.2 shows that the average prices in Korr are at the lowest (USD 30.226). Korr market is one of the important feeder markets in the region. The low prices reflect the infrastructural difficulties that raise transaction costs and limit access to regional markets (Roba *et al.*, 2017).

Prices are highest in Isiolo market than in the three closest markets (Acherspost, Merille, and Korr). The three markets are mostly sources of supply to Isiolo market. Moreover, Isiolo mean prices are also higher than those of Lekuru, where the trade flow of goats between the two markets is limited. Lekuru however has the highest coefficient of variation (CV), suggesting it has more price volatility than the rest. The mean price in Moyale is the highest (USD 60.5). Although it is located the furthest from the other markets, the high prices exhibited indicate the

Table 4.1: Summary of the Price Levels for Goats Traded in the Sampled Markets

Market Names	Obs	Mean	Std. Dev.	Min	Max	Skew.	CV
Isiolo	43	55.588	4.06	44.554	64.487	-0.446	7.303735
Acherspost	41	53.307	7.068	34.433	66.067	-0.335	13.25905
Merrile	43	40.25	4.974	28.053	59.406	0.984	12.9913
Korr	42	30.226	3.706	23.432	37.884	0.086	12.26097
Lekuru	42	47.03	8.24	33.964	69.307	0.9	17.52073
Moyale	43	60.5	9.034	45.05	85.396	0.319	14.93223

Note: Std. Dev. is the standard deviation; Obs is the observations; Skew is the skewness; CV is the coefficient of variation. Data from some of the markets were only available for 41 or 42 weeks.

possibility of trade flow (in the bid to explore possible arbitrage) from the other sampled markets.

4.3 Stationarity Tests and Estimating Optimal Lags

Table 4.2 shows the stationarity tests using both ADF and PP tests. As earlier mentioned, ADF could have a low statistical power to reject the null hypothesis and thus both tests were conducted for validation. Despite the common finding that most price series in the agricultural rural markets are non-stationary, each of the tests confirmed the stationarity of price levels for all markets except Korr. However, the null hypothesis of the absence of stationarity is rejected after the first deference of the price series. The lack of stationarity in price levels for Korr market could be linked to high transaction costs associated with its remoteness. The price series were included in the cointegration equation in their first difference i.e., all are *I* (1).

Table 4.2: Unit Root Tests Using Augmented Dicker Fuller and Phillips-Perron

Market Name	Augmented Dicker Fuller (ADF)		Phillips Perron (PP)	
	Levels	1st Difference	Levels	1st Difference
Isiolo	-5.677**	-11.993***	-5.544***	-12.282***
Acherspost	-6.352**	-13.517***	-6.367***	-13.742***
Merille	-7.131**	-7.007***	-7.503***	14.107***
Korr	-2.521	-10.115***	-2.537	-7.051***
Moyale	-3.119**	-10.111***	-2.985**	-15.069***
Lekuru	-4.009***	-9.308***	-4.247***	-12.515***

Note: ***, **, and * denotes 1%, 5%, and 10% significant levels respectively. The significance levels for each of test values for ADF and PP shows at what point we observe stationarity.

Table 4.3 shows the results for various model selection criteria. From this, the optimal number of lags included in the cointegration, and the VECM were estimated. The result of the Akaike

Table 4.3: Description of the Optimal Lags Included in the Cointegrations Equation

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-454.893	-	-	-	696340	24.805	24.8664	24.9792*
1	-430.907	47.973	16	0	455198*	24.3733*	24.6803*	25.2441
2	-416.885	28.044	16	0.031	523634	24.4803	25.0328	26.0476
3	-405.749	22.272	16	0.135	741731	24.7432	25.5413	27.0072
4	-388.318	34.862*	16	0.004	815589	24.6658	25.7096	27.6264

Note: Akaike's Final Prediction Error (FPE), Akaike Information Criterion (AIC), Hannan-Quinn information criterion (HGIC), Schwarz's Bayesian Information criterion (SBIC). All the information criteria show how well a model explains the variation in the outcome.

Information Criterion (AIC) shows that including one lag into the price series equations would be optimal. The AIC test is commonly used due to its simplicity. The best model examined is one in which the value of the information criterion is the lowest. In this case, a model with one lag has an AIC of 24.3733.

4.4 Cointegration

Table 4.4 shows the results of the Johansen tests for cointegration. The results show that the Eigen-max statistics are larger than the 5% critical values in the 5 maximum ranks. This means there are a maximum of five cointegrated market price series equations. It implies the price series of the sampled markets exhibit both short and long-run relationships. This further justified the use of VECM, which accounts for both the short- and long-run market price series relationships.

Table 4.4: Johansen Test for Cointegration Results

Maximum rank	Eigenvalue	Eigen-max statistic	5% critical value
0	-	50.6011	39.37
1	0.71777	48.7988	33.46
2	0.70476	27.9313	27.07
3	0.50256	17.1166	20.97
4	0.34813	13.1497	14.07
5	0.28017	7.3463	3.76
6	0.16778	-	-

Note: The null hypothesis is Ho; there is no cointegration in any of the price series. The decision criterion is the comparison between the magnitude of the Eigen-max statistics and the 5% critical value in each row i.e., we reject the null hypothesis if the Eigen-max statistic is larger in magnitude than the 5% critical value. For instance, the rank "0" means that there is no cointegration equation in any pair of the series i.e., if the Eigen-max statistic was lower than the 5% critical value.

Furthermore, the Engle granger test was also estimated to check for consistency as shown in Appendix IA, Table A1. The results show that the absolute value of the test statistic (-5.78) was greater than the 5% critical values (-5.140) and thus allowing for the rejection of the null hypothesis. In this case, the results for both tests are similar.

4.5 Vector Error Correction Model

Table 4.5 and 4.6 show the VECM short-run equilibrium estimates for six sampled markets obtained from estimating equation 3.6. They contain results used to infer causality in the short run and the error correction parameter used to infer convergence to long-run equilibrium. The regression table was originally one long table, but it was separated into two to allow for simple presentation and visualization. The results of three markets (Isiolo, Acherspost, and Merille), are presented in Table 4.5.

In the Isiolo market prices equation, there is no significant variable. It indicates that in the short run, market price shocks in other markets do not significantly affect prices in this market. This means that shocks in other markets are small but does not imply that the markets are not integrated (von Cramon-Taubadel, 2017). As mentioned earlier, most of the sampled markets act as feeder markets for Isiolo; prices are lower and located closer to the production catchments. The absence of a pastoral market that significantly causes short-run price changes in Isiolo implies that price dynamics in this market could be caused by shocks in other larger markets outside the region e.g., terminal markets in the cities.

The coefficient for speed of price adjustment in Isiolo markets is negative and significant. This indicates a significant (57.2%) correction of the weekly market shocks and convergence into long-run equilibrium. In the Acherspost market price equation, only its prices are causing significant variation in the short run. Based on the sign on the error correction parameter, there are indications of long-run convergence but no significant causal relationships. This suggests the presence of high inefficiency within the market, despite being connected with good roads and telecommunication networks. It also suggests that its closeness to Isiolo market could be limiting the generation of reasonable price difference for any exploration of arbitrages. Merille market price equation shows prices in Isiolo market having significant short-run causal effects. A unit prices change in Isiolo market causes a significant short-run decrease in prices in Merille of 56.3%. However, Acherspost, which is closer to Merille than Isiolo, has a positive and significant short-run effect on prices in Merille market. A unit change in prices in Acherspost causes a 26.8% increase in prices in Merille market. The error correction parameter coefficient is positive and significant at 1%. This indicates the presence of significant long-run causal effects, but limited convergence to long-run equilibrium.

Table 4.5: VECM Short-Run Estimates for Isiolo, Acherspost, and Merille Markets Prices

Dependent variables	Independent variables	Coeff.	SE
Isiolo Market prices			
	Speed of price adjustment (L._ce1)	-0.572***	0.169
	Isiolo market prices	-0.246	0.15
	Acherspost market prices	0.058	0.07
	Merille market prices	-0.059	0.102
	Korr market prices	0.235	0.145
	Moyale market prices	0.088	0.101
	Lekuru market prices	0.106	0.085
	Constant	-0.001	0.013
Acherspost market prices			
	Speed of price adjustment (L._ce1)	-0.412	0.36
	Isiolo market prices	-0.474	0.32
	Acherspost market prices	-0.51***	0.15
	Merille market prices	-0.156	0.218
	Korr market prices	0.251	0.309
	Moyale market prices	-0.06	0.215
	Lekuru market prices	0.151	0.181
	Constant	-0.003	0.027
Merille market prices			
	Speed of price adjustment (L._ce1)	1.067***	0.267
	Isiolo market prices	-0.563**	0.238
	Acherspost market prices	0.268**	0.112
	Merille market prices	0.153	0.162
	Korr market prices	-0.079	0.23
	Moyale market prices	0.131	0.159
	Lekuru market prices	-0.032	0.135
	Constant	-0.003	0.02
Number of observations	39		

Note: *** p<0.01, ** p<0.05, * p<0.1. All prices were transformed into natural logs. SE stands for standard errors while Coeff stands for coefficient.

Table 4.6 shows the short-run market price relationships for Korr, Moyale, and Lekuru Markets. The error correction parameters are also shown for each market price equation. This parameter is significant for Korr and Moyale. In both cases, it indicates the presence of significant long-run causal relationship and convergence to long-run equilibrium at a speed of 62.9% and 51.6% respectively.

Table 4.6: VECM Short-Run Estimates for Korr, Moyale, and Lekuru Markets Prices

Dependent variables	Independent variables	Coeff.	SE
Korr Market prices			
	Speed of price adjustment (L._ce1)	-0.629***	0.174
	Isiolo market prices	0.309**	0.155
	Acherspost market prices	-0.051	0.073
	Merille market prices	-0.068	0.106
	Korr market prices	-0.026	0.15
	Moyale market prices	0.127	0.104
	Lekuru market prices	0.31***	0.088
	Constant	-0.007	0.013
Moyale market prices			
	Speed of price adjustment (L._ce1)	-0.516***	0.195
	Isiolo market prices	-0.075	0.173
	Acherspost market prices	0.159*	0.081
	Merille market prices	-0.276**	0.118
	Korr market prices	0.088	0.167
	Moyale market prices	-0.571***	0.116
	Lekuru market prices	0.065	0.098
	Constant	0.011	0.014
Lekuru market prices			
	Speed of price adjustment (L._ce1)	0.228	0.357
	Isiolo market prices	-0.218	0.318
	Acherspost market prices	0.003	0.149
	Merille market prices	0.019	0.217
	Korr market prices	-0.288	0.307
	Moyale market prices	0.052	0.213
	Lekuru market prices	-0.696***	0.18
	Constant	0.014	0.027
Number of observations	39		

Note: *** p<0.01, ** p<0.05, * p<0.1. All prices were transformed into natural logs. SE stands for standard errors while Coeff stands for coefficient.

In the Korr price equation, Isiolo and Lekuru's market prices have positive and significant coefficients. This indicates the presence of short-run causal relationships between the prices in these markets. A unit change in Isiolo market prices causes a 30.9% change in Korr market prices. Similarly, a unit change in Lekuru market prices causes a 31% change in Korr market prices. Both Lekuru and Isiolo are large regional markets, and this relationship implies that Korr market receives its price signal from these markets.

The Moyale market price equations show a negative and significant ($P<0.01$) short-run causal relationship with its own lagged prices. A similar relationship also exists with Merille ($P<0.05$) and Acherspost ($P<0.1$) markets. In the short run, a unit change in Merille and Acherspost markets prices causes 27.6% and 15.9% changes in Moyale market prices respectively. The difference in magnitude and levels of significance between Merille and Acherspost market prices could be linked to the proximity of the markets.

While Moyale is at the furthest edge of the trading route, Merille is nearer to the Moyale market than Acherspost. Hence, with or without trade flows, the difference suggests distance influences the strength of the price signal transmissions between the markets. Furthermore, Lekuru market price lags only matter in its price equation. The absence of significant price signal transmission with the current sets of markets suggests that prices in Lekuru market could be influenced by other markets in the same trading route. This is even true as no significant long-run price equilibrium convergence is depicted by the error correction parameter.

Table 4.7 shows the VECM long-run price equations, from which the error correction term is generated. Isiolo market was used as the outcome variable. The results show evidence of the long-run impact of Merille, Korr, and Lekuru market prices on Isiolo market prices. Merille market prices have a positive impact on Isiolo markets; a unit change in Merille market prices causes a 70.3 % change in Isiolo market prices. Prices in Lekuru and Korr markets have a negative long-run impact on Isiolo market prices.

In the long-run, a unit increase in Lekuru market price causes a decrease in Isiolo market prices by 35.6%. Similarly, a unit increase in Korr market prices causes a decrease in Isiolo market prices by 18.4%. Acherspost market, which is closer to Isiolo market, does not depict any long-run price relationship. This suggests that despite the proximity, both markets are independent, with inherent frictions. Also, the weak long-run relationship between Isiolo and Moyale could be attributed to the long distance between the markets. Furthermore, Moyale market prices could be influencing other market prices across the Kenyan-Ethiopia border.

Table 4.7: Description of the VECM Long-Run Estimates

Outcome	Markets prices (beta)	Coef.	SE
Error correction parameter (_cel)	Isiolo market prices	1	-
	Acherspost market prices	0.135644	0.111166
	Merille market prices	-0.70299***	0.114806
	Korr market prices	0.183746**	0.088397
	Moyale market prices	0.072672	0.073069
	Lekuru market prices	0.356921***	0.088489
	Constant	-4.25624	-

Note: *** p<0.01, ** p<0.05, * p<0.1. The direction of effect of the coefficients in this regression are interpreted oppositely i.e., a negative coefficient is interpreted as a positive and vice versa.

4.6 Conclusions and Policy Recommendations

The objective of this study was to establish the state of regional market integration in pastoral livestock markets amidst increased mobile phone access and improvement in physical infrastructure. Weekly market price data for goats, collected through a mobile phone-based crowdsourcing initiative, conducted for 43 weeks (November 2009 to September 2020) was analysed. The unit-roots test using both ADF and PP tests confirmed the presence of stationarity in the first difference in all the market price series. The Johansen cointegration test confirmed the presence of cointegration in up to five pairs of the market price series. As a result, the VECM framework was used to estimate the short and long-run causal price relationships. From this framework, the speed of price adjustment from price shocks was also estimated. Most markets exhibited high speed adjustments into a long-run equilibrium implying low information asymmetry and market frictions.

Short-run causal relationships between markets operating along the same trading route were dominant. Markets along the Moyale-Isiolo trading route showed indications of efficient price transmission. This was despite other markets like Korr being located away from the Tarmac Road. This implied that good and reliable road connectivity plays a significant role in price transmission. It was notable that Isiolo market prices, which is the largest urban market in the region, had no significant short-run price relationships with other sampled markets. It however causes significant short-run effects on prices of other markets (Merille and Korr) which were deemed to be important surplus markets in the region (Roba et al., 2017). It was also evident that Moyale border market has significant short-run relationships with closer inland markets (Merille and Acherspost). Smaller markets (e.g., Korr), located off the tarmac roads, hardly transmit significant price signals. They mostly receive shocks from other larger markets in the region. Generally, the presence of short-run causal relationships between markets in the region provides evidence of efficiency in information flow between markets located on the Moyale - Isiolo tarmac road.

The long-run causal relationship between regional terminal markets and other intermediate and feeder markets in pastoral settings exists. This is evident for both markets that experience a regular flow of trade (Merille and Korr) and those that do not trade (e.g., Lekuru Market). This further indicates evidence of an efficient flow of price information such that traders can exploit possible arbitrage opportunities whenever they occur. It is also important to note that the pastoral border market prices have a weak long-run causal relationship with in-land regional markets. Furthermore, the relationship between perfectly placed inland markets (Isiolo and Acherspost) warrants further investigation. They exhibit weak long-run and short-run relationships despite being closest to each other, connected with tarmac, and having good communication networks.

The findings from this study provide fundamental insights into the current state of market integration in pastoral markets. Using high-frequency data generated through an innovative crowdsourcing process represents a huge milestone in collecting market price data from rural agricultural settings. It demonstrates that crowdsourcing is a viable option to counter the common challenges of missing data characteristics of these markets. The research findings show that a higher proportion of price variation in the intermediate markets in the region is due to its shocks while variation in smaller markets originates from the larger markets. As such, intermediate markets are senders of price information while the feeder markets are receivers of price information. This indicates a unidirectional price transmission i.e., from deficit markets to surplus markets. Although there is an indication of long-run relationships, the characteristic of the short-run relationship is a deterrent to rural agricultural market transformation.

Notwithstanding the current improvement in pastoral livestock markets' efficiency, more investments, beyond communication technologies, are needed to reduce market frictions in feeder markets operating close to production catchment areas. For markets currently without good connectivity, further investments in physical infrastructure like roads and modern markets would be useful. In all the feeder markets, which are currently price takers, approaches that empower producers, through cooperatives and increasing market information densities could strengthen their negotiating power and the resultant price transmission. Given the limitation of using only price data for our analysis, leveraging on the applicability of crowdsourcing in such contexts, future studies should explore study designs that capture transaction costs and actual livestock trade flows to provide more insights into the state of market integration in the region.

CHAPTER FIVE

HOUSEHOLD MARKET PARTICIPATION

5.1 Introduction

This chapter provides the results and discussions of objective two of this study. It begins with a pooled summary description of the panel households' characteristics. A summary of the outcome variable, disaggregated by ruminant sizes i.e., small, and large ruminants. This is followed by a description of mobile phone network coverage of the study sites and households' mobile phone access dynamics. Furthermore, a detailed description of mobile phone use in terms of information sources accessed and information types searched by pastoralists are also provided. This chapter also includes regression estimates and discussions on the effects of the duration of mobile phone access on market participation. The regressions results are disaggregated by ruminant size. Conclusions and recommendations are provided at the end of the chapter. Additional material and results, mainly for robustness checks, are provided in Appendix IB.

5.2 Panel Survey Household Socio-Economic Characteristics

Table 5.1 shows pooled summary statistics for the sampled households over the seven rounds of the survey. The final column shows test for differences in means between the observations linked to households with access to mobile phones with those that do not. Notably, the mean duration of access to mobile phones and network coverage is 1.8 and 3.4 years respectively. This means that, on average, sublocations were connected to network before households accessed mobile phones. Moreover, the duration of access to mobile phones by household members is higher than the mean for household heads owning mobile phones. Access to mobile phones without necessarily owning them could be through sharing with neighbours and friends (Parlasca *et al.,* 2020). It is also possible that they share the information obtained through mobile phones (Aker & Mbiti, 2010). For this reason, years of access to mobile phones by any member of the survey households is used as the main source of variation in the subsequent analysis.

Partially sedentary households constitute 60.7% of the sampled households, followed by 37.1% of fully sedentary households and the remainder of 2.2% are nomadic. The results also show that income from livestock sources is almost half (53.7%) of the total income for all sampled households. Further disaggregation in Table B.2 shows a 67% and 79% livestock income ratio for partially sedentary and nomadic households respectively. Fully settled households have a 30% livestock income ratio. These statistics suggest that reliance on non-livestock income sources increase as pastoralist reduce the intensity of mobility.

Table 5.1: Pooled Sample (2009-2020) Summary Statistics for Pastoral Households

Variables	Mean	SD	Min	Max	Diff
Mobile phones access variables					
Any member duration of access (years)	1.829	3.615	0	25	1.466***
Duration sublocation has connectivity* (years)	3.446	4.153	0	18.056	-0.14**
Duration household head owned a phone (years)	1.39	3.177	0	25	0.086
Household head own phone (yes=1)	0.294		0	1	0.657***
Household variables					
Household size	5.985	2.455	1	19	0.196***
Years of schooling	2.376	4.794	0	23	-0.018
Financial literacy index	0.546	0.362	0	1	0.049***
Age (years)	49.939	16.113	18	96	-0.097
Financial savings (yes=1)	0.323		0	1	0.067***
Marital status (Married= 1	0.765		0	1	0.011
Group membership (yes= 1)	0.718		0	1	0.047***
Gender (male =1)	0.635		0	1	0.054***
Livestock income ratio	0.537	0.445	0	1	-0.048***
Total livestock herded (TLUs)	15.191	23.484	0.000	483.286	0.086***
Total livestock owned (TLUs)	12.640	18.516	0.000	367.929	0.092
Household settlement category					
Fully settled	0.371		0	1	0.049***
Nomadic	0.022		0	1	-0.003
Partially settled	0.607		0	1	-0.057***
Household Remittance category					
Autarky	0.014		0	1	-0.002
Net receiver	0.742		0	1	-0.083***
Net giver	0.243		0	1	0.087***
Distance to the main market (km)	146.181	54.187	21.834	320.497	-0.01
Distance to the main town (km)	74.716	46.548	0.413	224. 124	-0.001
Sample					6,369

Note. *** p<0.01, ** p<0.05, * p<0.1. The difference (Diff) is the regression coefficient of each variable on the mobile phone access dummy while controlling time effects. As discussed, the panel data models used ensures that the true effect of duration is determined by controlling both observed and unobserved heterogeneity. Variable* is the Instrumental Variable used.

The mean livestock owned is less than livestock herded. This suggests the existence of strong traditional social systems that support access to livestock dividends, even for households that do not own any livestock. These could be important channels through which some households derive income and food. It is also notable that 74% of the households are net remittance receivers i.e., either through local informal channels between households and/or development agencies. The mean distances to the main market and town are 146 km and 76 km respectively. Although there are other smaller and closer towns and markets within each community, pastoralists must move their livestock to regional markets to access better prices (Roba *et al.*, 2017). This suggests a possible hindrance to market participation.

Table 5.2 shows statistics of the outcome variable disaggregated by small ruminants (SR) and large ruminants (LR). It shows that a higher proportion of pastoralists are net sellers (55.8%) of SR and autarky (70.7%) of LR. Only a small percentage (26.2%) of households participate in the markets as net sellers of LR, despite having higher LR livestock holdings (both herded and owned). This indicates that a bulk of recurrent consumption expenditures are supported by sales of SR.

Most variables differ by member access to mobile phones. Notably, given the negative sign of the regression coefficient for test of difference means, the number of SR and LR net sellers reduce for households with access to mobile phones. This is also true for quantities of LR sold. Both purchases and sales prices for LR and SR differ significantly with access to mobile phones. In this way, access to mobile phones could be associated with higher mean prices. In both SR and LR categories, less than 10% of pastoralists participate in the market as net buyers of livestock. However, the average LR and SR TLUs intake through informal exchanges is higher than the intake through purchases. Further disaggregation of the outcome variable by market participation categories in Table B.1 in Appendix IB, also shows consistent participation in the informal exchanges, especially in intake. This statistic affirms that pastoralists mostly use markets for the sale of livestock rather than the purchase of breeding stock (Little *et al.*, 2014). Restocking is mostly filled through non-market channels (informal exchanges) such as births, loaning, and borrowing, among others (Lutta *et al.*, 2020).

Table 5.2: Summary Statistics of Outcome Variables Disaggregated by SR and LR

Variables	Small Ruminants			Large Ruminants		
	Mean	**SD**	**Diff**	**Mean**	**SD**	**Diff**
Market participation categories						
Net buyer (1)	0.061		0.023***	0.031		0.009**
Autarky (2)	0.381		0.055***	0.707		0.086***
Net seller (3)	0.558		-0.063***	0.262		-0.095***
Livestock stock (TLUs)						
Herded	4.027	5.717	-0.109	11.616	19.962	-0.744
Owned	3.701	5.376	-0.172	9.314	15.199	-0.538
Quantities traded (TLUs)						
Purchased	0.057	0.384	0.040***	0.141	1.201	0.012
Sold	0.543	1.351	-0.084***	0.748	2.631	-0.092
Average Prices (KES)						
Selling price	2436.855	1237.513	216.42***	21493.9	11268.2	2,196.15***
Purchase price	2270.45	1723.227	191.7	19220.5	10760.11	1,471.02
Informal livestock exchange (TLU)						
Offtake	0.08	0.431	0.046***	0.286	1.455	0.087**
Intake	0.159	0.476	-0.049***	0.483	1.886	-0.178***
Sample	6,369			6,369		

Note: *** p<0.01, ** p<0.05, * p<0.1. The difference (Diff) is the regression coefficient of each variable on the mobile phone access dummy while controlling time effects. Informal livestock exchanges include forms like dowry, gifts, borrowing, and other traditional exchanges. KES in column 1 mean Kenya Shillings.

5.3 Network Connectivity, Mobile Phone Access, and Years Connected

Table 5.3 shows that access to mobile phones has rapidly expanded across the survey region in the past decade. On average, across sampled sublocations, it increased from l0% in 2009 to more than 90% in 2020. There are however a few sublocations, mostly those connected earlier, with 100% of households having access (column 6) in 2020. The experience in using mobile phones, as measured by the years of access (columns 2 & 5), increased from an overall mean of 1.2 to 9 years from 2009 to 2020 respectively. However, in three sublocations (Dakabaricha, Dirib gombo, and Sagante), by 2009more than 20% of the households accessed mobile phones (column 3), have more than 4 years of experience in accessing mobile phones and with connection to the network before 2009. These three sublocations are located close to Marsabit town, which is the county headquarters and the largest town in the county. No household reported accessing mobile phones before the sublocations were connected.

Table 5.3: Description of Sublocation Connectivity and Household Access to Mobile Phones

	2009 Means (Baseline, N= 924)			2020 Means (Endline, N=863)		
	1	2	3	4	5	6
Name of Sublocation	**Years area connected**	**Years HH access MP**	**HH accessing MP (%)**	**Years area connected**	**Years HH access MP**	**HH accessing MP (%)**
DAKABARICHA	4.00	7.06	0.56	13.51	18.06	1.00
DIRIB GOMBO	1.43	4.28	0.24	9.29	15.28	0.99
SAGANTE	0.97	4.16	0.20	6.65	15.16	0.77
BUBISA	0.37	0.00	0.11	6.17	9.27	0.91
EL GADE	0.04	0.00	0.02	5.08	6.97	0.85
KALACHA	0.01	0.00	0.01	5.72	6.23	1.00
TURBI	0.65	0.00	0.12	6.82	10.21	0.98
KARARE	0.33	0.00	0.05	5.60	4.71	0.89
KARGI	0.00	0.00	0.00	3.65	8.08	0.95
KURKUM	0.00	0.00	0.00	4.03	9.02	0.92
LOGO LOGO	0.28	0.00	0.04	7.12	7.95	0.98
ILLAUT	0.00	0.00	0.00	2.58	1.32	0.72
LONTOLIO	0.17	0.00	0.03	3.52	6.26	0.84
LOIYANGALANI	0.24	2.99	0.10	4.36	13.99	0.79
NGURUNIT	0.10	0.00	0.05	3.81	1.35	0.84
SOUTH HORR	0.60	0.00	0.17	7.29	10.91	0.88
Average	0.51	1.21	0.10	5.90	9.36	0.91

Note: HH stands for households; MP stands for mobile phones. Columns 1 and 4 are the mean number of years a sublocation had network connectivity at the time of the survey and are the instrumental variables used in this analysis. Columns 2 and 5 contain the mean number of years households reported having access to mobile phones by sublocation. Column 3 and 6 represents the proportion of households that reported having access to mobile phones by sublocation, without consideration of frequency.

5.4 Mobile Phone Use Frequency and Market Information Search

Figure 5.1 illustrates the reported rates of use of mobile phones across time. More than 50% of the survey households in 2009 had never used a mobile phone. This proportion reduced to less than 5% in 2020. By 2020, most respondents (85%) used mobile phones every day with the remaining (15%) using phones at least once a week. There is clearly an opportunity for the daily use of mobile phones, which is observed in a large portion of the sample by 2020, to reduce information asymmetry within and between the communities.

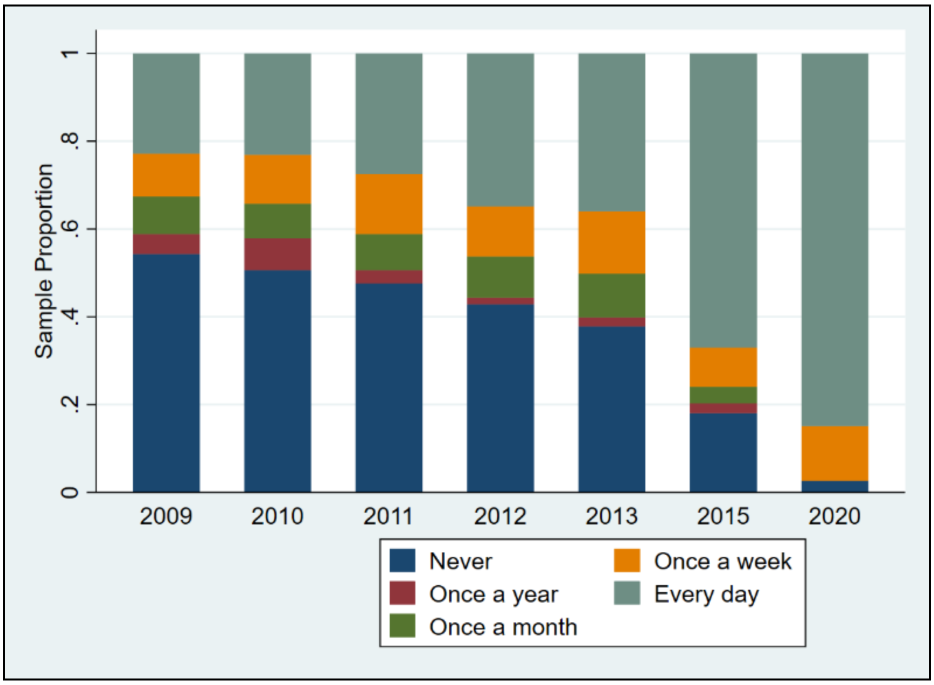


Figure 5.1: Proportion of Households Using Mobile Phones at Different Frequencies in Each Survey Round.

Figure 5.2 shows that livestock market price is the most common type of market information searched. It is also important to note other complementary information such as security, diseases, and water availability which are important considerations for pastoralists to participate in markets. Word-of-mouth and mobile phones are the most common channels used to obtain market information. This suggests complementarity between mobile phones with common information channels used rather than substitution. Furthermore, Table B.4 in the Appendix shows that households that use mobile phones to search for market information have a longer duration of access to mobile phones than users of other channels. This finding shows that the duration of access to mobile phones influences how individuals access market information. It also suggests that a shorter duration of access may not be sufficient to transform the market search behaviours of pastoralists using mobile phones.

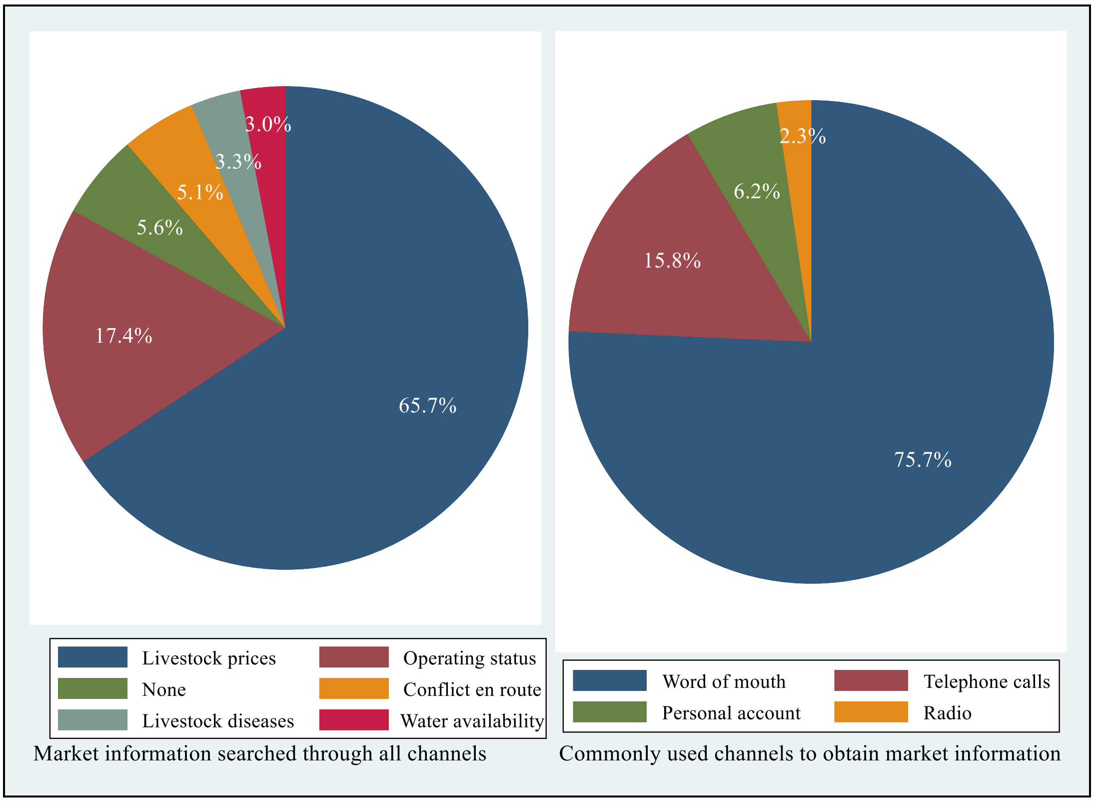


Figure 5.2: Market Information Searched, and Channels Used.

Figure 5.3 illustrates the SR selling behaviours of pastoralists before and after access to mobile phones. It depicts an increase in quantities of sales in all periods before access to mobile phones and a gradual decrease after access. The inverse relationship between quantities sold across the years after access indicates that pastoralists have a unique market participation behaviour in response to increased access to mobile phones. Households with access to mobile phones receive significantly higher prices as shown in Table 5.1 and thus this may have contributed to reduced quantities sold if sales were primarily targeted to meet specific expenses.

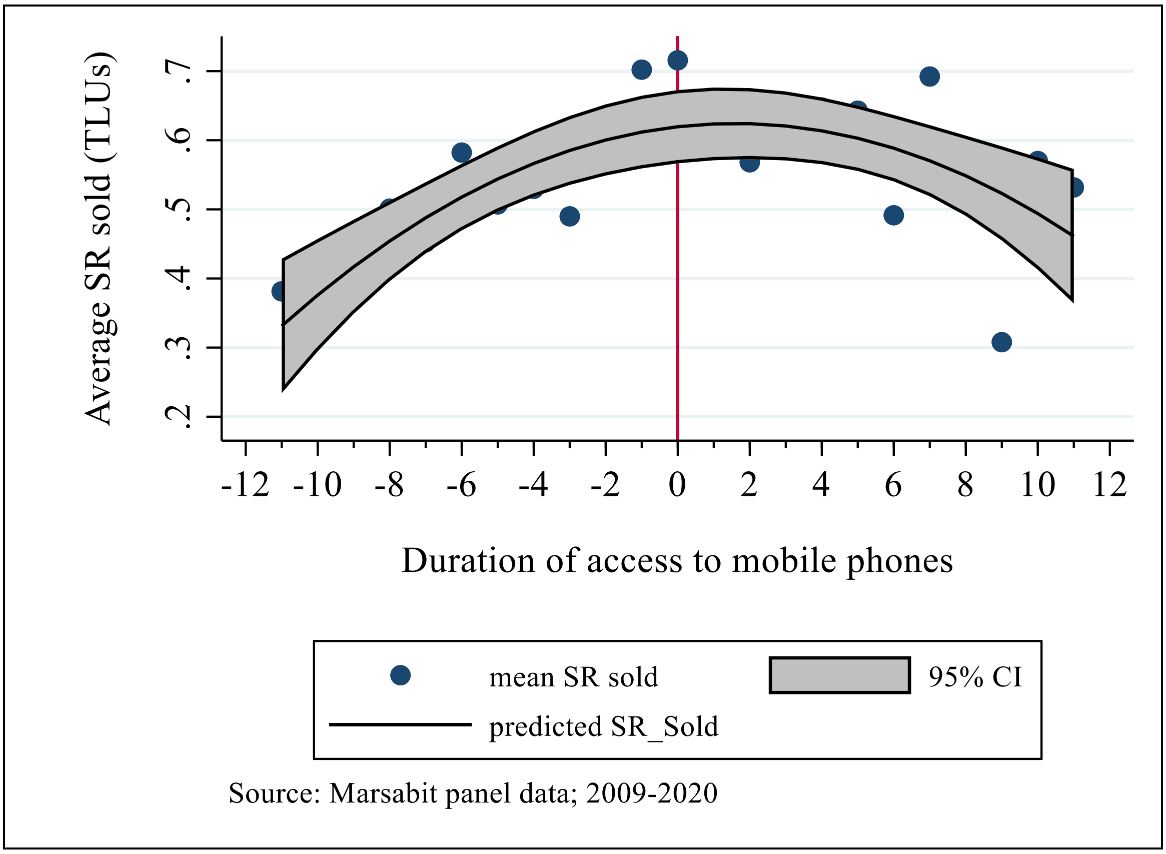


Figure 5.3: Trends of SR Sales in Durations before and After Access to Mobile Phones.

5.5 Effects of Duration on Market Participation

Regression results presented in this section entail the ordered and continuous market participation outcomes. In each of the outcomes, separate results are presented for SR and LR. In all estimations, the duration of access to mobile phones variable is instrumented by the duration of access to network connectivity in each sampled sublocations. Only the results of the second stage (outcome equations) are shown in the main text. The estimates of the selection equations, that adjust the effects of confounding factors, are shown in Table B.5 in the Appendix. Estimation of market participation using the Tobit model specification, which assumes joint market participation decision, is also presented in Table B.6 in the Appendix, for robustness checks.

5.5.1 Small Ruminants Market Participation

Table 5.4 presents the results of estimating equation 3.9, using the ordered market participation outcome. The outcome variable was specifically constructed from a combination of TLU values for SR. The coefficient estimates and marginal effects for the three ordered categories

Table 5.4: Ordered Probit Estimates for the Small Ruminant Market Participation

			Marginal effects		
Variable	**Coeff**	**SE**	**Net buyer**	**Autarky**	**Net sellers**
Duration of mobile phone access (years)	-0.094**	0.012	0	0.001	-0.001
Goat and Sheep herded (TLUs)	0.048***	0.007	-0.005	-0.009	0.014
Camel and Cattle herded (TLUs)	-0.003*	0.001	0	0	-0.001
Household Size	0.012	0.009	-0.001	-0.002	0.003
Years of Education	-0.005	0.004	0	0.001	-0.001
Financial literacy index	-0.079	0.053	0.008	0.015	-0.023
Age of household head (years)	-0.003**	0.001	0	0	-0.001
Gender of household head (1=male)	-0.067	0.053	0.007	0.013	-0.02
Savings (dummy, 1= yes)	-0.029	0.042	0.003	0.005	-0.008
Marital status (1= married)	0.146**	0.058	-0.011	-0.02	0.032
Group membership status (1=yes)	0.018	0.048	-0.002	-0.003	0.005
Partially sedentary settlement	0.153***	0.042	-0.016	-0.029	0.045
Nomadic settlement	0.123	0.15	-0.013	-0.023	0.036
Net remittance receiver	-0.053	0.038	0.005	0.01	-0.015
Net remittance giver	0.037	0.058	-0.004	-0.007	0.01
Livestock income ratio	1.247***	0.054	-0.127	-0.229	0.356
Distance to main livestock market (log)	0.089*	0.052	-0.013	-0.017	0.03
Informal SR intake (TLUs)	-0.103**	0.046	0.011	0.019	-0.029
Informal SR offtake (TLUs)	-0.054	0.035	0.006	0.01	-0.016
ρ^*	0.626***	0.066			
Pseudo Loglikelihood	-15400				
Number of observations	5900				

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard errors (SE) are clustered at the household level. Fully sedentary is the base category for household settlement type. ρ^* is the correlation parameter between errors of the outcome and selection equation. It is significantly different from zero, so the duration of access is endogenous. Because it is positive, it indicates that unobserved factors that cause an increase in the chance of high duration of access tend to also enhance market participation.

are presented. The model used permits meaningful interpretation of the direction of the coefficients but not magnitude.

The coefficient for the duration of access to mobile phones (duration) is negative and significant ($P < 0.05$). This means an increase in duration significantly reduces the likelihood of increased market participation. The marginal effects indicate that duration significantly reduces the probability of being net sellers, although the value is very small. It however increases the likelihood of being an autarky or net buyer.

A few control variables influencing SR market participation are significant. High volumes of SR herded by households significantly increase the likelihood of market participation. However, the effect of LR herded on SR market participation is negative. This implies that pastoralists with more LR herds are more likely to sell fewer SRs. The results also show that households that derive a large proportion of their total household income from livestock are more likely to participate in the markets as net sellers of SR. A high livestock income ratio however reduces the likelihood of being a net buyer or autarky. This finding suggests that off-farm income attenuates active SR market participation.

Households that are partially sedentary are more likely to be active in SR market participation than those that are fully sedentary. Fully sedentary households have lower livestock holdings and a lower livestock income ratio than other categories (Table B.2 in the Appendix). This suggests that the significant difference observed could be driven by limited marketable herds and high income from off-farm options by the base category. Experienced herders, as indicated by the age variable, are less likely to be active in SR market participation. However, married household heads are more likely to be active in SR market participation. Distant households are more likely to sell more than those living closer to main regional markets. However, the quantity of SR intake through informal channels significantly causes a decrease in the likelihood of market participation as net sellers. It encourages net-buying and remaining self-sufficient.

Table 5.5 presents the results of estimating equation 3.9, using the continuous outcome, comprising observed positive SR sales and purchases. As earlier noted, quantities traded (purchased or sold) are mostly influenced by proportional transaction costs. As such, access to improved transportation and communication technologies reduce these costs and subsequently improves trade. The interaction of duration and distance provides a mechanism for linking the effect of the two variables on the continuous market participation outcome. The coefficient for the duration is positive while that of its interaction with distance is negative and significant. This means that the magnitude and direction of the effect of duration vary with changes in distance. Duration positively affects quantities traded for households closer to the main market and vice versa. For instance, using the FE estimate (Coeff = 0.684, SE=0.227), one year increase in duration causes an increase in SR sales by 0.684 TLUs when distance is assumed to be zero. This value decreases in magnitude and direction as distance increases, becoming negative for households living beyond 115.6kms, which is slightly below the mean distance to the main market (146.2km). This indicates that an increase in duration could have relaxed market information constraints, but distant households remained constrained by factors that inhibited market participation.

The household-to-market distance RE coefficient is positive and significant for sales. This implies that households without access to mobile phones increase sales of SR by 17.5% as the distance to market increases by 2.7kms. While this may outrightly look counterintuitive, it is plausible to link the increased sales to declining terms of trade associated with a positive correlation between distance and transaction costs. The negative sign of the interaction coefficient also indicates that the effects of distance change in magnitude and direction as duration increases. As such, using the RE estimate (Coeff =0.175, SE = 0.061), the coefficient for distance is less than zero after 2.97 years. This implies that distant households begin to reduce sales after accessing mobile phones for more than three years. It further indicates that households need a longer duration to overcome market access barriers and subsequently change their market participation behaviours.

The results also show interesting relationships between pastoralist households' characteristics and the extent of market participation. Regarding household wealth, herding larger numbers of goats and sheep is also related to higher SR market participation. The RE estimates show an increase in both volumes of purchases and sales by 0.048 and 0.051 TLUs respectively. However, unlike the negative effect of herding large volumes of camels and cattle in the selection stage, the effect on the extent of market participation is positive but not significant. Household size significantly and positively influences SR sold. This could be linked to high consumption expenditure requirements by large households. Moreover, net remittance givers and receivers sell lesser SR than those that give as much as they receive or don't give or receive altogether (autarky).

Table 5.5: FE and RE Estimates of the Impact of Duration on Quantities of Small Ruminant Sales and Purchases

	Purchases				Sales			
Variables	**FE**		**RE**		**FE**		**RE**	
	Coeff	**SE**	**Coeff**	**SE**	**Coeff**	**SE**	**Coeff**	**SE**
Duration of mobile phone access (years)	1.317	0.804	0.312	0.321	0.684***	0.227	0.353**	0.148
Goat and Sheep Herded (TLUs)	0.054	0.053	0.048**	0.023	0.024*	0.012	0.051***	0.015
Camel and Cattle herded (TLUs)	0.004	0.007	0.003	0.006	0.004	0.004	0.002	0.004
Household Size	-0.02	0.055	-0.029	0.03	0.085***	0.025	0.032**	0.015
Years of Education	0.044	0.028	0.01	0.01	0.018	0.027	0.011	0.009
Age of household head (years)	-0.009	0.009	0.005*	0.003	-0.007	0.005	0.003*	0.002
Gender of household head (1= Male)	0.224	0.245	0.320***	0.099	0.053	0.145	0.365***	0.061
Financial savings (1=yes)	-0.039	0.109	0.190**	0.091	0.137*	0.073	0.243***	0.073
Financial Literacy Index	0.199	0.243	0.252*	0.143	0.072	0.078	0.13	0.079
Marital status (1= married)			-0.305***	0.102			-0.243***	0.072
Group membership status (1= member)	0.322	0.253	-0.042	0.092	-0.024	0.074	-0.006	0.055
Partially sedentary category	-0.258	0.175	-0.285*	0.166	-0.188*	0.097	-0.221***	0.078
Nomadic	0.224	0.301	-0.114	0.179	-0.122	0.137	-0.204	0.144
Net remittance receiver	-0.044	0.154	0.069	0.085	-0.116*	0.06	-0.153***	0.057
Net remittance giver	-0.415	0.342	-0.048	0.124	-0.076	0.079	-0.021	0.072
Livestock income ratio	-0.75	0.932	-1.671**	0.668	0.281	0.294	-0.037	0.256
Distance to main livestock market (log)			-0.084	0.176			0.175***	0.061
Duration * Distance to the main livestock market	-0.301*	0.168	-0.022	0.076	-0.144***	0.046	-0.059**	0.029
Inverse Mills Ratio (IMR)	-1.001	1.771	-3.496**	1.418	-0.782	0.695	-1.502**	0.624
Goat and sheep average buying price (log)	0.072	0.128	-0.001	0.102				
Goat and sheep average selling price (log)					-0.557***	0.077	-0.421***	0.07
Informal SR intake	0.126	0.143	0.036	0.062	-0.004	0.063	-0.074	0.065
Informal SR offtake	0.290	0.174	0.166	0.144	0.255**	0.121	0.258**	0.108
Constant	1.044	1.762	2.605*	1.546	4.534***		2.723***	
Number of observations	593		593		3701		3701	

Note: *** p<0.01, ** p<0.05, * p<0.1. Std. Err. adjusted for 1,064 clusters in hhid. Fully sedentary is the base category for both partially sedentary and nomadic households. Remittance autarky is the base category for net remittance receivers and givers. The subsample with positive purchases is smaller thus the magnitude and direction of the coefficients could be due to noise. Many control variables for quantities sold are significant suggesting that besides price, multiple factors influence livestock sales.

Households with financial savings sell significantly more SR than those without. Similarly, a high financial literacy index significantly is related to an increase in the SR purchased. The causal effects of these financial indicators suggest the existence of commercial-oriented pastoral households. Male-headed households significantly trade more volumes than female-headed households. This could be linked to the labour-intensive nature of pastoralism, mostly due to the need for migration, and long-distance trekking to vibrant markets.

In terms of income sources, a higher livestock income ratio significantly causes a reduction in quantities purchased. Table B.1 in the Appendix shows that net sellers have a higher livestock income ratio and larger herds. Due to the larger herd sizes, it is more likely that intake is mainly through births, and thus herd expansion through purchases may not be a feasible option. Although the likelihood of participating in the market declined with age, the intensities seem to significantly increase. Further investigations could provide more clarity on this inconsistency.

An increase in the selling price significantly causes a decrease in sales volumes. This is counterintuitive if market-oriented production is considered a motive consistent with pastoralists. Furthermore, previous studies showed an increase in price that is associated with access to mobile phones (e.g., Zanello, 2012; Tack & Aker, 2014; Fan *et al.*, 2018). This finding indicates that income thresholds from sales of SR exist among pastoral communities. The threshold is stationary to the extent that households are price inelastic.

Offtake through informal non-market channels significantly causes an increase in quantities of sales. Previous studies show that offtake through these channels does not affect market participation (e.g., Bellemare & Barrett, 2006). While this study shows evidence of informal exchanges causing variation in market participation, further research is needed to uncover the mechanisms and in-depth relationships.

5.5.2 Large Ruminants Market Participation

Table 5.6 presents the results of estimating equation 3.9, using the ordered market participation outcome for LR. The coefficient estimates and marginal effects for the three ordered categories are also presented. Like the results in Table 5.4 only the direction of the coefficients' estimates provides meaningful interpretation. Notably, the results show that the coefficient for the duration of access to mobile phones is negative and significant ($P < 0.01$). Regarding the marginal effects, an increase in duration causes a reduction in the likelihood of being a net seller but increases the likelihood of being a net buyer or an autarky.

This causal relationship of duration with the ordered market participation outcomes is like that of SR. This is despite the difference in production cycles and pastoralists' social connection between SR and LR. LR takes longer periods to mature, is considered the main asset, and has a stronger cultural attachment to pastoralists than SR. As such, they are traded less frequently and whenever sold, the revenue is commonly used to cover relatively different sets of household expenditures from those covered by sales of SR.

Herding large volumes of LR significantly enhances its market participation. However, the effect of goats and sheep holdings on LR market participation is not significant. Also, high LR volumes herded significantly reduce the likelihood of being autarky, but instead increase the likelihood of being a net seller. The level of households' dependence on livestock income, as indicated by the livestock income ratio, increases the probability of being a net seller. It is also evident that large households are more likely to be net sellers. Like in SR market participation, this finding provides further indication of sales observed being mostly driven by households' expenditure.

Social groups, which is an important institutional characteristic, significantly enhance LR market participation. This is different from SR market participation whose effect was not significant. This suggests that actions and outcomes of collective action are more concentrated and impactful on LR herding activities than

SR. Similarly, a higher financial literacy index significantly enhances LR market participation. Both indicators often incentivize commercialization and thus their effects on LR market participation are consistent with the long-standing finance literature. The effect of gender of the household head is negative and significant. It implies that female heads are more likely to sell LR. This could be attributed to the higher vulnerabilities of women to climate and income shocks (Balehey *et al*., 2018).

Table 5.6: Ordered Probit Estimates for the Large Ruminant Market Participation

			Marginal Effects		
Variables	**Coeff**	**SE**	**Net buyer**	**Autarky**	**Net Seller**
Duration of mobile phone access (years)	-0.047***	-0.012	0.001	0.002	-0.002
Goat and Sheep Herded (TLUs)	0.001	-0.004	0	0	0
Camel and Cattle herded (TLUs)	0.007***	-0.002	0	-0.001	0.002
Household Size	0.034***	-0.009	-0.002	-0.007	0.009
Years of Education	-0.002	-0.005	0	0	-0.001
Financial Literacy Index	0.115**	-0.053	-0.008	-0.024	0.032
Age of household head (years)	0	-0.001	0	0	0
Gender of household head (1= Male)	-0.108**	-0.049	0.007	0.023	-0.03
Financial savings (1=yes)	-0.074*	-0.043	0.005	0.015	-0.02
Marital status (1= married)	0.038	-0.056	-0.002	-0.005	0.006
Group membership status (1= member)	0.189***	-0.048	-0.014	-0.038	0.051
Partially sedentary settlement	0.086**	-0.041	-0.006	-0.018	0.024
Nomadic settlement	0.131	-0.144	-0.009	-0.028	0.037
Net remittance receiver	0.029	-0.038	-0.002	-0.006	0.008
Net remittance giver	0.074	-0.058	-0.005	-0.016	0.021
Livestock income ratio	0.901***	-0.053	-0.062	-0.188	0.25
Distance to main livestock market (log)	-0.324***	-0.055	0.022	0.068	-0.09
Informal LR intake	-0.022	-0.014	0.002	0.005	-0.006
Informal LR offtake	0.024	-0.014	-0.002	-0.005	0.007
Constant	-0.635**	-0.271			
ρ^*	0.284***	-0.098			
ll	-15100.00				
Number of observations	5900				

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard errors (SE) are clustered at the household level. Fully sedentary is the base category for both household settlement categories. Remittance autarky is the base category for both remittance categories. ρ^* is the correlation parameter between errors of the outcome and selection equations. Time dummies include all the seven survey rounds.

Distance to the main market negatively and significantly ($P < 0.01$) affects market participation. This implies that being further away from the main market reduces the likelihood of participating in LR markets. Moreover, distant households are less likely to be net sellers. This finding indicates that the decision to participate in the market is inhibited by the presence of high transaction costs linked to increasing distance to the main livestock market. However, when movement is a trait embedded in the search for pasture, as indicated by the significance of sedentary household settlement, it leads to enhanced market participation. It implies that a settlement category in the pastoral system that does not permit sufficient migration, as exhibited by the fully sedentary (the base category), limits engagements through market participation. It is also worth noting that informal livestock exchanges do not significantly influence market participation decisions.

Table 5.7 presents the factors that affect the intensity of LR market participation. The results show that the FE coefficients for both duration of access to mobile phones and its interaction with the distance variable are significant ($P < 0.01$) for the purchases equation only. The findings indicate that the quantities of purchases decrease as the duration of access increases. Based on the magnitude and direction of the coefficient of the interaction term, the effect tends towards zero as the distance to the main market increases. This implies that connected distant households benefit more than those closer to markets. It is also important to note that the sub-sample linked to these findings is small and thus the observed effects could likely be noise in the data. The coefficient for duration in other equations i.e., the RE estimates for purchases in both the FE and RE sales equations, are not significant. However, distance to the main market constrains the intensity of market participation for households without access to mobile phones.

There are several significant control variables in the market participation intensities equations. As noted earlier, LR trade could be mostly driven by other factors besides transaction costs. The results show that herding large volumes of LR significantly enhances market participation. This effect is consistent for both decision and intensity outcomes. However, herding large volumes of SRs significantly ($P < 0.01$)

reduces the quantities of LR sales. This is consistent with the earlier explanation that LRs are hardly sold to cover recurrent consumption expenditures. This implies that pastoral households prefer selling SR whenever they have stock of both SR and LR, to fill income needs.

Household size positively and significantly ($P < 0.01$) causes an increase in both sales and purchases. This indicates that large households trade more than households with fewer members. Given the similarity in direction of influence in both sales and purchases equations, the interpretation of this finding could be linked to the variation in herding labour endowments within the households. Larger households have access to a wider pool of labour that could be leveraged to meet the high migration requirement in herding LR. The positive and significant coefficients for household settlement categories support this interpretation in that both nomadic

Table 5.7: FE and RE Estimates of the Impact of Duration on Quantities of Small Ruminant Sales and Purchases

	Purchases				Sales			
	FE		RE		FE		RE	
	Coeff	**SE**	**Coeff**	**SE**	**Coeff**	**SE**	**Coeff**	**SE**
Duration of mobile phone access (years)	-12.675***	4.235	-0.984	0.775	0.82	1.923	0.558	1.199
Goat and Sheep Herded (TLUs)	0.175	0.137	0.048	0.066	-0.072**	0.03	-0.059**	0.025
Camel and Cattle herded (TLUs)	0.152***	0.016	0.121***	0.026	0.183***	0.045	0.176***	0.054
Household Size	1.108***	0.38	0.730***	0.282	0.613***	0.206	0.640***	0.198
Years of Education	0.114	0.185	0.014	0.058	-0.042	0.133	0.03	0.02
Financial Literacy Index	2.280*	1.336	2.400**	1.033	1.710***	0.583	2.006***	0.727
Age of household head (years)	0.029	0.072	0.004	0.017	0.066**	0.031	0.018***	0.005
Gender of household head (1= Male)	-4.510*	2.542	-1.723*	1.028	-2.996***	0.701	-1.435***	0.44
Financial savings (1=yes)	-2.990***	0.78	-0.941	0.682	-1.257***	0.442	-1.200**	0.501
Marital status (1= married)			0.502	0.913			0.667***	0.223
Group membership status (1= member)	6.687***	1.212	3.840**	1.582	3.567***	0.85	3.318***	1.104
Partially sedentary category	3.345***	0.879	2.189***	0.746	1.962***	0.509	1.604***	0.541
Nomadic settlement category	6.008***	1.583	3.273**	1.312	3.483***	1.079	2.855***	0.959
Net remittance receiver	0.662	0.875	0.868	0.654	0.542*	0.299	0.383	0.234
Net remittance giver	3.032**	1.321	2.181**	0.928	1.362***	0.377	1.500***	0.372
Livestock income ratio	30.336***	4.692	16.250**	6.681	19.404***	4.075	17.836***	5.347
Distance to main livestock market (log)			-4.719**	2.222			-5.751***	1.768
Duration * Distance to market	2.313***	0.892	0.021	0.151	-0.41	0.371	-0.291	0.234
LR average buying price (log)	0.847	0.803	-0.587	0.512				
LR average selling price (log)					-1.021***	0.236	-0.960***	0.289
Inverse Mills Ratio (IMR)	44.263***	6.46	23.798**	9.309	27.115***	6.329	25.167***	8.147
LR Informal intake (TLUs)	-0.175	0.242	-0.167	0.141				
LR Informal offtake (TLUs)					0.513***	0.134	0.443***	0.141
Constant	-90.973***	13.296	-15.223	10.4	-43.558***	11.774	-12.590**	5.812
N	279		279		1893		1893	

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard errors (SE) are clustered at the household level. Fully sedentary is the base category for both household settlement categories. Remittance autarky is the base category for both remittance categories.

and partially sedentary households trade more than the fully sedentary households. Moreover, households with higher livestock income ratio trade significantly (P > 0.05) more than those who dismally depend on livestock.

The indicators of capital have a significant influence on the trade of LR. High financial literacy, an indicator of financial capital, causes an increase in the volumes traded. Although the coefficient for education is not significant, the significance of the financial literacy variable suggests the importance of non-academic channels of financial knowledge e.g., through training by development agencies common in the region. This notion could also be deduced from the positive and significant influence of the group membership variable, which is an indicator of social capital. It indicates that groups play a key role in enhancing the trade of LR. This could be through the dividends of capacity building and collective action common in groups. Moreover, households with higher financial savings trade less LR.

The coefficient estimates for net remittances givers for both purchases (P > 0.05) and sales (P > 0.01) are significant. It is logical to assume net remittance givers to be wealthier than the other remittance categories. As such, the increasing volumes of purchases could be linked to more ability to expand stock while the sales are part of managing their surpluses. The coefficient for informal livestock offtake is positive and significant (P > 0.01). This indicates that having more offtake through informal channels causes an increase in sales. This relationship could be attributed to variation in livestock endowments between households, such that those with high offtake through informal channels also have more sales through the formal market.

The RE estimates for average LR purchase prices indicate declining purchases with an increase in prices. Although the coefficient is not significant, the interpretation is consistent with economic theory i.e., quantity demanded reduces as prices increase. However, the quantities sold significantly (P > 0.01) reduce as prices increase. This is counter-intuitive if commercialization is assumed to be the main driver of production and marketing. Like SR, this finding also suggests that sales of LR are linked to meeting specific expenditure thresholds such that volumes are reduced when higher prices are received.

The results also show that older household heads sell more LR than younger counterparts. Accumulation of wealth through herding LR, sometimes over the lifetime of pastoralists, may limit younger pastoralists from herding large volumes of LR. In this sense, it is more likely that older household heads have more flexibility to sell since they may have accumulated more stock than practically possible for younger heads. This interpretation is consistent with the positive causal relationships between herd volumes and trade (especially sales).

5.6 Conclusion and Policy Recommendations

Access to mobile phones continues to be important in the rural agricultural transformation debates. In market participation studies, the most common mechanism promoted is the transformation through the reduction of transaction costs associated with market information search. This pathway has been analysed by defining and measuring access to mobile phones in diverse ways. This study contributes further to the discussion by defining access in terms of the duration in years that households have had access to mobile phones. It was hypothesized that a longer duration of access to mobile phones increases market participation. In this case, this would be represented as an increase in the likelihood that the pastoral participants of the study are net sellers rather than net buyers of livestock. Seven rounds of panel data, collected from 2009 to 2020 from pastoral communities in northern Kenya were used to test the hypothesis.

The descriptive statistics showed that most pastoralists participate in markets as net sellers. They are more likely to be net sellers of SR than LR. We interpret this to mean that SR sales are often used to cover household recurrent consumption expenditure. In both cases, only a few are net buyers. It is also notable that the informal exchange of livestock continues, even for households that are in the autarky category of market participation. This shows that besides trade, informal exchanges between households play an important role in supporting livelihoods. Moreover, the high percentages of non-trading pastoral households indicates that transaction costs, fixed or proportional, are still a deterrent to their supply response. There is also notable variation in dependence on livestock income by household settlement type. Partially sedentary and nomadic pastoralists have a higher livestock income ratio than those fully settled. This implies that livestock markets play an important role in facilitating trade, but with varying intensities dependent on settlement type.

Unequal network coverage expansion led to observable spatial variation in the duration of access to mobile phones and frequency of use. An increase in duration and frequency of access means that most pastoralists are more accustomed to using mobile phones in their economic activities – both in production and marketing. Notably, access to mobile phones complements other traditional channels, predominantly “word of mouth”, in searching for market information from local sources. The study also shows that besides market price information, other information types, such as availability of forage, water, and security, are crucial in enabling market access.

The analysis showed that changes in duration cause variations in both the likelihood and intensities of market participation. The effect varies in magnitude and direction depending on the households’ distance to the main livestock market. For households located near markets, increases in the duration of access to cell phones increase market-oriented production as measured by net animals sold. However, for households that are far from markets, increased duration of cell phone access reduces quantities of livestock sold. These results also show an indication of substitution between SR and LR sales. The LR market participation reduces as volumes of SR herded increase and vice versa. With evidence of demand for diverse market information types e.g., security enroute, water and forage, the decreasing sales by distant households shows that access to mobile phones is not sufficient to overcome all barriers to market access. It is, therefore, likely that distant households transferred the digital dividends into unprecedented herd build-up through a reduction in sales.

To support market-oriented production, both private and public sector players need more investments beyond increasing access to mobile phone technologies. Increasing consistent availability of water, forage, and security would facilitate inclusive increased market access. Similarly, strengthening complementary efforts that support herd build-up could also be beneficial. This could include recent attempts to financialise risk markets through novel index-based livestock insurance (Jensen *et al.*, 2017). In addition, further improvement of market and road infrastructure near production catchments would minimise the need for pastoralists to access regional markets for better prices. It also reduces the effects of barriers currently difficult to break through access to mobile phones. With the duration of mobile phones increasing over the unforeseeable future, implementing the investments would provide the necessary environment for expansion and re-orientation of market participation motives for rural households.

CHAPTER SIX

CROWDSOURCING FOR MARKET INFORMATION

6.1 Introduction

This chapter presents and discusses the results of objective three of the study. It begins with an illustration of high-frequency market price data collected using the KAZNET micro-tasking platform. This is followed by a description of the contributors engaged, their participation, and levels in response to the incentives provided over the experiment period. Regression results using panel data Tobit model are then shown. This includes conditional and unconditional regressions for both direct and spillover effects of the incentives on contributor participation. Alternative specifications and their regression results are provided in Appendix IC.

6.2 Livestock Market Information Collected Through the KAZNET Platform

Figure 6.1 illustrates weekly mean goat prices from 10 livestock markets in northern Kenya, disaggregated by contributor-assessed animal body condition. As expected, prices are related to animal body condition; fat goats are more expensive than moderate ones, which are more expensive than thin or emaciated goats. Alulu *et al.* (2020) used this data to show that more than half of the variation in the price of goats is explained by body type. Here it is noted that the red vertical line between March and April 2020, marks the onset of restrictions in Kenya related to the COVID-19 pandemic. During the x weeks after the restrictions (i.e., to the right of the vertical red line), movement was restricted in Kenya and most field operations, including field-based data collection activities, were disrupted, which highlights another advantage of crowdsourced data collection processes. Interestingly, the COVID-19 pandemic has no discernible impact on price movements.

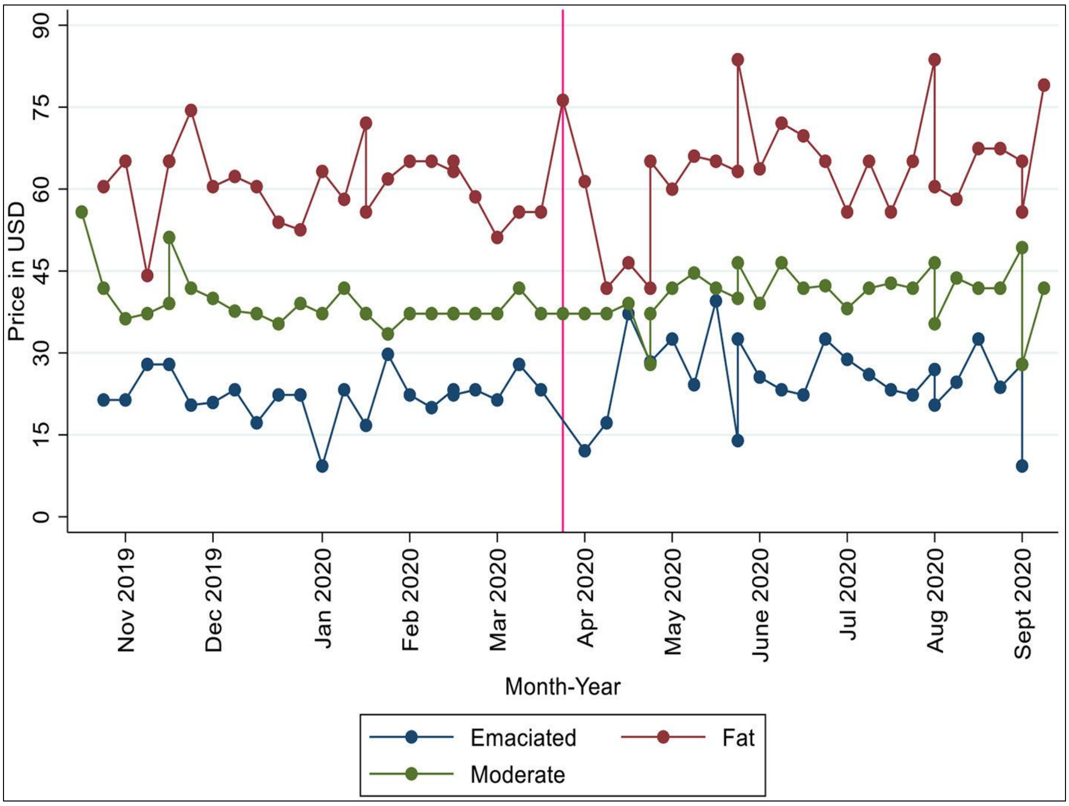


Figure 6.1: Weekly Mean Goat Price by Body Condition in 10 the Livestock Markets.

6.3 Contributors' Socio-Market Characteristics

The study focused on the changes in the outcomes of average weekly submissions for the livestock price tasks and the weekly sum of household welfare submissions in response to the treatments over the experimental periods. Table 6.1 provides a summary of the contributors' socio-market characteristics and their task submission levels. The statistics show that the mean weekly submissions increased in each treatment period over the 19 weeks for both weekly livestock price and daily household welfare tasks. In both the first and second treatments, livestock prices task submissions were above the payable limits, as depicted by the means and standard deviations, indicating possible change associated with the treatments. In terms of contributors' characteristics, 73% are members of social groups, own livestock on different scales, are mostly youth of 29 years, and 62% have at least a secondary level of education. There is also a balance in the composition by gender. Most contributors reported pastoralism as their main occupation. There is, however, a slight variation in distance from contributors' residences to the livestock markets, and half of the sampled markets are located close to the Moyale-Nairobi tarmac road.

Table 6.1: Summary Statistics of the Contributors' Socio-Market Indicators

Variable	Mean	SE	Min	Max
Average weekly livestock prices submissions				
Week 1- 6 (before treatment)	2.577	2.807	0	11.333
Week 7-12 (treatment one)	3.496	3.313	0	15.333
Week 13-19 (treatment two	4.121	3.801	0	16.500
Weekly sum of household welfare submissions				
Week 1- 6 (before treatment)	1.164	1.65	0	6
Week 7-12 (treatment one)	1.364	1.9	0	6
Week 13-19 (treatment two	1.617	1.905	0	6
Market connectivity (near tarmac=1)	0.540		0	1
Group member status (yes=1)	0.730		0	12
Gender of the contributor (male =1	0.587		0	1
Education level (high level= 1)	0.619		0	1
Distance to the market (in Kilometers)	6.127	7.688	1	35
Contributor CAPI experience (yes=1)	0.746		0	1
Contributors' age	29.206	7.784	21	57
TLU owned contributor	14.702	23.423	0	112
Contributor Main occupation				
Pastoralist	0.444		0	1
Casual labor	0.190		0	1
Government employee	0.079		0	1
Livestock trader	0.079		0	1
Livestock market agent	0.063		0	1
Shop keeper	0.143		0	1
Experiment period (weeks)	10.000		1	19

Notes: This table provides descriptive statistics of the outcome and explanatory variables considered in the analysis. The second column presents mean values, the third column provides standard deviations (SE)—except for binary variables, and the fourth and fifth columns provide the minimum (min) and maximum (max) values, respectively.

Raw data of weekly average submissions for the livestock price task over the 19 weeks was used to generate Figure 6.2 There is an increasing participation trend observed in both groups before the treatments. This could be attributed to a gradual acquaintance with the KAZNET platform and possible excitement commonly observed during the early stages of rolling out similar crowdsourcing platforms (Bayus, 2010). Upon stabilizing, the control group, however,

Figure 6.2: Contributors' mean submissions over the experiment period.

maintained somewhat uniform submission levels across the entire period. Treatment one had limited effects in the first half of the treatment period. The additional information provided in week 13 had an incremental influence on the participation rates. It indicates that the contributors comprehended the script and increased their submissions, building from the second half of treatment period 1 until week 18. The drop in participation close to the end of the experiment is attributed to the slowdown in market activity occasioned by the COVID-19 pandemic announcements in mid-March 2020 and the subsequent formal market closures.

Figure 6.3 shows density plots overlayed on histograms of submission distribution by treatment group over treatment periods. The graphs demonstrate a low likelihood of a few outliers causing variation in the submission trends depicted in Figure 6.2. All the positive submissions are normally distributed across and within the groups. This implies that the effect of the treatment is unlikely to be driven by a few outliers in the groups at any given treatment period.

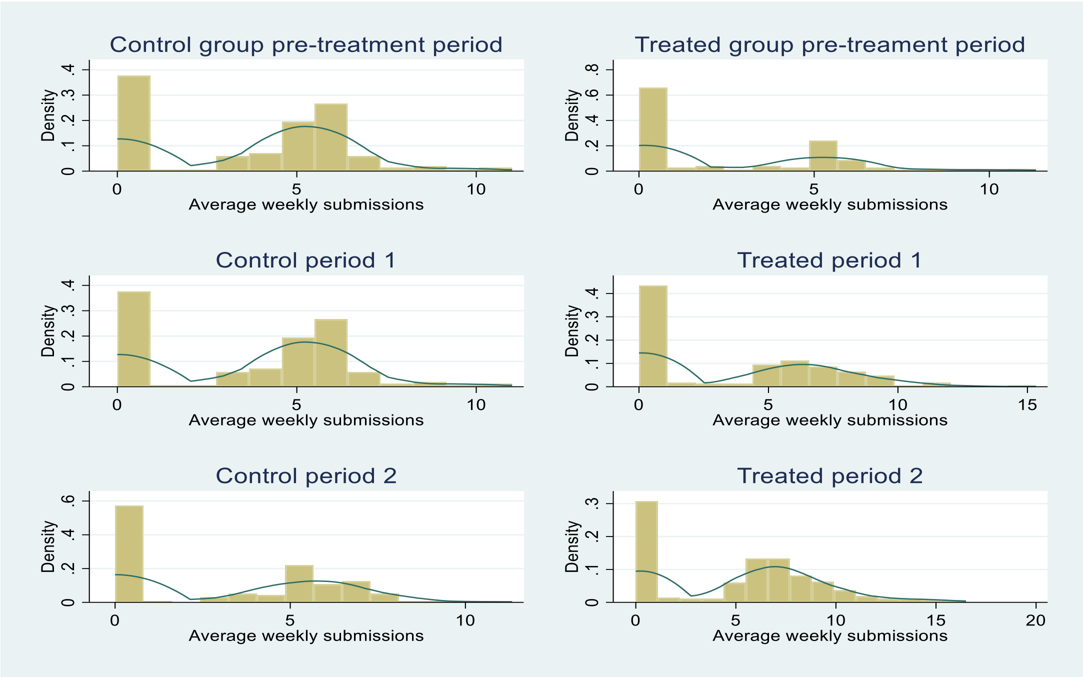


Figure 6.3: Histogram and Kernel Density Plots for Contributor Submissions.

Many zeros in each group justify using limited dependent regression models. For this reason, the Tobit model was preferred for use in this study.

6.4 The Tobit Model Results

The results begin by showing the effect of the two treatments on the contributors' participation in micro-tasking on market data that were used to generate the price information treatment content; this is referred to as the direct effect. It is followed by an analysis of the effect of the treatment on contributors' participation, as measured by the number of submissions per week, on tasks that were not used to generate the content in the price information treatment; this is referred to as the spillover effect of the treatment.

6.4.1 Direct Effects of Incentive Treatments on Contributors' Participation

The results in Table 6.2 how the conditional panel Tobit regression model estimates of the two treatments on the participation of pastoral contributors in micro-tasking. Participation levels are measured by the average weekly submissions of individual livestock price and quality tasks for all animal types (camels, goats, sheep, and cattle), conditional on their availability on scheduled market days. For instance, if on a market day, only three animal types were available for trade, then a contributor's weekly average would be obtained by dividing the total submissions by three. This is regardless of whether the contributor performed the tasks for all three animal types, i.e., they have performed one, two, or all three.

Conditional regression coefficients were obtained by estimating equation 3.21, i.e., while including the relevant controls (Z_i). Estimates of average effects on the Tobit latent outcome variable i.e., the extensive margins, which represent marginal effects using the censored sample are presented. In addition, the intensive margins, which represent the treatment effects conditional on participation being above zero, i.e., the truncated data, are also presented. Table C.1 in appendix IC shows the unconditional Tobit regression results aimed at demonstrating the robustness of the coefficient estimates obtained from the conditional regression.

The results show that adding access to livestock market price information to the control incentives (monetary) does not increase latent participation relative to the control. However, when access to the price information is combined with information on how the quality of the price information that they are accessing is sensitive to the quality and quantity of their contributions, participation increases dramatically ($P < 0.01$). The script treatment led to an increase in participation levels by an average of 3.6 submissions above the pre-treatment period.

In terms of actual participation levels, the script treatment increased submissions by an average of 1.4 submissions. For those contributors that had positive submissions, the script treatment increased their average submissions by 0.5 above the levels observed in the pre-treatment period. It is also important to note that the shared price information significantly ($P < 0.05$) affected participation for the censored and truncated samples. These results suggest that the

Table 6.2: Direct Conditional Tobit Regression Results

Participation; Average weekly submissions	**Average effect on Latent variable**	**Marginal effects**	
		Censored sample	**Truncated sample**
Group effect	-0.128	0.867	0.569
	(1.336)	(0.924)	(0.667)
Treatment period one	1.027**		
	(0.511)		
Treatment period two	0.069		
	(0.764)		
Price information	0.154	0.672**	0.481**
	(0.843)	(0.321)	(0.234)
Price information + script	3.581***	1.352***	0.945***
	(1.013)	(0.456)	(0.327)
Market connectivity	1.15	0.739	0.532
	(1.05)	(0.679)	(0.489)
Group membership status	3.224**	2.073***	1.491***
	(1.296)	(0.798)	(0.586)
Gender of contributor	0.727	0.468	0.336
	(1.437)	(0.914)	(0.657)
Education level of Contributor	-2.002	-1.287	-0.926*
	(1.411)	(0.895)	(0.647)
Distance to market	-0.1	-0.065	-0.046*
	(0.077)	(0.049)	(0.352)
Digital survey experience	-0.168	-0.108	-0.078
	(1.357)	(0.874)	(0.628)
Age of the contributor	0.069	0.044	0.032
	(0.083)	(0.053)	(0.385)
TLU owned by contributor	0.021	0.014	0.010
	(0.019)	(0.012)	(0.008)
Main occupation			
Casual Labor	-4.397***	-2.558***	-1.863***
	(1.471)	(0.715)	(0.542)
Govt Employee	0.869	0.660	0.495
	(2.154)	(1.667)	(1.266)
Livestock Trader	-1.192	-0.829	-0.606
	(1.955)	(1.300)	(0.945)
Market agent	-1.196	-0.831	-0.608
	(2.780)	(1.847)	(0.134)
Shop keeper	-3.231*	-2.017**	-1.462*
	(1.86)	(1.032)	(0.759)
Sigma_e	3.764***		
	(0.226)		
Number of observations (N*T)	1140	1140	1140

Note: *** p<0.01, ** p<0.05, * p<0.1 Standard errors (Bootstrap) are provided in parentheses. Pastoralism is the base category in the main occupation variable.

script, which gave added elaboration on the link between the tasks and the feedback, motivated the pastoral crowd workers to increase participation. The increased participation could be attributed to the contributors' understanding of the value of additional submissions in increasing the accuracy of the market price information disseminated.

Results in Table 6.2 also demonstrate that a few contributor traits and their institutional characteristics had significant impacts on participation. While the contributors were selected based on having a primary activity within the target livestock markets, the results suggest that being a casual labourer or shopkeeper reduces the expected average submission by 4.3 and 3.2 respectively, when compared with contributors in the base category, i.e., pastoralism. The trend is similar for both the extensive and intensive margins. The two groups of contributors could be busier during market days when most of the livestock price tasks are performed. The shopkeepers could be busy serving the above-normal customer numbers while the casual laborers could lean on optimizing wages from the increased number of pieces of work occasioned by high market-day activities. It is, however, unexpected for the livestock market agent coefficient to be negative, although not significant, because their main activity during the market day is closely linked to the micro-tasking activity.

Contributors who are members of social groups have positive and significant participation levels when compared to non-members. This is consistent across extensive and intensive margins. This result is not surprising as social groups tend to motivate members to be more open to innovations by being information seekers in rural agricultural settings (Okello *et al*., 2014). Moreover, agricultural social groups act as an effective channel for production and marketing intervention (Bizikova *et al.,* 2020).

Longer distances to the market cause a reduction in contributors' participation level. This is despite being cognizant of the constraints that would arise from selecting contributors from distant settlements. Furthermore, 68% of the contributors indicated that they were using motorized means to the markets. Given these preconditions, it should be less cumbersome to access the markets and subsequently have a limited negative impact on participation levels. It is, however, plausible to argue that, besides the pursuit of main occupation and micro-tasking, there is a likelihood that contributors plan to engage in a long list of time-demanding activities since market days only happen once a week. In such settings, this result indicates that effective participation in micro-tasking would require more localized targeting of contributors to minimize low participation occasioned by increasing marginal efforts for any added unit of distance.

6.4.2 Spillover Effects of Incentive Treatments on Contributor's Participation

Table 6.3 shows conditional regression results of the effect of the two treatments on the contributor's participation in the daily household welfare task. Results for the unconditional regression are presented in Table C.2 in the Appendix. Participation was censored at 0 and 6, to correspond to the skipped day without submissions and consistent daily submissions within a week, respectively. Only a single submission per day was accounted for.

Equation 3.21 was estimated by changing the outcome variable to correspond to the participation levels in the household welfare task. Both treatments have positive coefficient estimates, but only the added elaboration script made the coefficients of the second treatment significant ($P < 0.01$). The incremental submissions resulting from the added script translate to approximately one and a half days more of desired participation in a week. Similarly, both the extensive and intensive margin estimates were positive and significant. This indicates that the market price information incentives had significant spillover effects. It suggests that the treated contributors were more likely to be consistent in making daily submissions of tasks that were not directly related to the treatment. One plausible way to interpret the results is to attribute the increased participation to contributors' increased understanding and acknowledgment of the overall value of the platform.

The education level of the contributor is negative and significant. It suggests that contributors with lower education were participating more frequently than their counterparts. The task being settlement-based, this observation partially implies that more educated individuals could have limited time to perform tasks more frequently. They could be seeking other jobs, most likely found in local towns, with higher marginal returns than community-based tasks. The main occupation did not matter in the household-based task as it did for market-day-based livestock prices tasks. This further supports the interpretation of linking reduced participation to increased competition for time allocation in some occupations (e.g., casual labor and shopkeeping) during the busy one-time weekly market days. However, contributors who are

Table 6.3: Spillover Conditional Tobit Regression Results

Participation; Average weekly submissions	Average effect on Latent variable	Marginal Effects Censored sample	Truncated sample
Group effect	1.340*	1.055*	0.747*
	(0.772)	(0.391)	(0.285)
Treatment period one	0.128		
	(0.369)		
Treatment period two	0.149		
	(0.478)		
Price information	0.347	0.161	0.115
	(0.444)	(0.152)	(0.109)
Price information +script	1.444***	0.548***	0.363**
	(0.560)	(0.202)	(0.146)
Market connectivity	0.436	0.231	0.167
	(0.753)	(0.402)	(0.289)
Contributor group membership status	1.163*	0.617*	0.445*
	(0.686)	(0.363)	(0.262)
Gender of the contributor	-0.185	-0.098	-0.071
	(0.828)	(0.437)	(0.316)
Education level of the contributor	-2.028**	-1.175**	-0.776**
	(0.836)	(0.460)	(0.330)
Contributor digital survey experience	1.090	0.578	0.416
	(0.834)	(0.449)	(0.323)
Age of the contributor	0.025	0.013	0.001
	(0.065)	(0.034)	(0.025)
TLU owned by contributor	0.001	0.000	0.000
	(.012)	(0.007)	(0.005)
The main occupation of the contributor			
Casual Labor	-0.653	-0.302	-0.224
	(0.993)	(0.457)	(0.339)
Govt Employee	1.564	0.930	0.668
	(1.413)	(0.913)	(0.659)
Livestock Trader	0.564	0.303	0.218
	(1.147)	(0.824)	(0.591)
Market agent	1.223	0.706	0.507
	(1.690)	(1.073)	(0.769)
Shop keeper	0.787	0.432	0.311
	(1.150)	(0.887)	(0.634)
Sigma_u	2.064***		
	(0.183)		
Sigma_e	2.283***		
	(0.164)		
Observations	1140	1140	1140

Note: *** p<0.01, ** p<0.05, * p<0.1 Standard errors (Bootstrap) are provided in parentheses. Pastoralism is the base category in the main occupation variable.

group members are more likely to significantly increase both average latent, actual, and intensive participation levels. This is consistent with the effect on market-based tasks. It indicates that social groups among pastoralists have a strong positive influence on information-seeking and sharing behaviors.

The mean submissions for the household welfare task were considerably low (Table 6.1). This shows a huge gap in achieving daily based high-frequency data from pastoral communities. While the treatment has great potential for increasing participation, understanding the gap requires considering the digital enabling environment. It is important to note that the conditions for the effective use of digital technology in pastoral settings are still evolving. For example, access to electricity to keep smartphones charged remains a challenge—without a home-based charging system, one must rely on external sources which are costly.

Although it is difficult to observe the input of remote work (Holmstrom & Milgrom, 2012), in this context, contributors should put in extra effort to support its effective functioning. It then implies that only sufficiently incentivized contributors would make an additional effort to keep their phones mostly usable for KAZNET. Thus, they achieve some degree of consistency in their weekly participation schedule. In contrast to the weekly market-based livestock prices and quality tasks which are completed once a week, the cycle of the daily task requires more contributor effort and motivation.

The findings demonstrate how monetary and non-monetary incentives could be combined to encourage contributor participation in micro-tasking. The piece rate payment structure used in the first six weeks before introducing the treatments substantially motivated the contributors to participate in the activity. It was also an integral part of the incentive structures used in the first and second information treatments. The use of monetary incentives in micro-tasking that relies on extrinsic motivation has been documented (Neto & Santos, 2018; Kittur *et al.,* 2013). Although this study does not compare monetary incentives with other possible extrinsic motivators, the results support the use of monetary incentives in real effort tasks. It further supports the feasibility of using piece rate payment structures in activities that have traditionally been rewarded with flat rate payment structures. Even though quality controls for tasks were performed, further experimental work on the effect of the incentive regime used in this study on the quality of submissions would be more fruitful.

The objective of testing whether providing information in the form of insights generated from the data submitted by the contributor supported the value of feedback in evoking intrinsic motivation. It also demonstrated the importance of clarity in the process and content of the feedback. The contributors may have found value in the feedback provided in the first treatments. However, they may not have linked the quality of the information to their participation levels. It is also important to note that aligning the motives of the crowdsourcer and contributors is a critical success factor for micro-tasking (Sharma, 2010). This interpretation is further supported by the positive and significant coefficient estimate in the second treatment when more clarity was given through the script.

While the increased participation could be attributed to the feedback reinforcing intrinsic motivation, it is also possible that it was filling market information gaps faced by the contributors and other pastoralists within their networks in the region. The finding supports the argument for the provision of feedback to users of digital platforms to enhance utilization, which is consistent with the finding by Eitzinger *et al.* (2019).

The additional results on the spillover effect of the information treatments could be interpreted as a benefit from contributors finding value in the information. There exists a close link between market activities and households' welfare because pastoralists depend on livestock and livestock markets for their livelihoods. For this reason, the value of shared information treatments is more likely to incentivize increased participation in household-level daily tasks. It then implies that the price information feedback was able to maximize the contributors' effort in both task categories. This interpretation is consistent with that of Aoyagi (2010) who argued that an optimal feedback policy maximizes workers' expected effort. As such, contributor participation in micro-tasking could be incentivised by a subset of appealing tasks with an ability to spill over an equivalent level of effort to other complementary tasks in the same activity.

A few coefficients estimate of the contributors' demographic and institutional characteristics were significant. The simplicity characteristic of micro-tasks is meant to allow basic digital device users to participate in micro-tasking without being limited by their traits and/or environment, as outlined in Kietzmann (2016). A good task design should increase the participation of contributors (Geri *et al.,* 2017). Consequently, the results of casual labor, education level, and shopkeepers require contextual interpretation. One would expect that these groups of contributors would participate more because the nature of their main occupation complements the micro-tasking activity. For example, a casual laborer, seeking dynamic and uncertain wage opportunities, should logically allocate reasonable time and effort to an almost certain wage opportunity like micro-tasking.

Similarly, highly educated contributors should be more aligned to technology-based labor markets and more likely to have a high propensity for timely market information. Hence, they would be more responsive to the participation incentives. Conversely, it is also plausible to suggest that market days are the peak of economic activity in these communities. Hence the two labor categories could be time-constrained, and effectively switching between tasks is untenable. Contributors with higher education tend to seek jobs with less marginal effort and possibly higher returns. It is also important to note that, unlike other occupations, micro-tasking has no formal obligation nor mechanism to punish participation (Howe, 2006). Therefore, additional research is needed to uncover more inclusive incentive regimes.

6.6 Conclusion and Policy Recommendations

Overall, the field experiment on incentivizing pastoral contributors to microtask provides insights that feed broadly and specifically into both the crowdsourcing and the agricultural information systems literature. Broadly speaking, the accomplishment of micro-tasking in pastoral areas of Kenya is a key indicator of the increasing potential of using digital systems in other rural and remote settings whose infrastructure is evolving and demand for high-frequency data is steadily increasing. In more specific lenses, MISs targeting pastoral settings should leverage the growing number of pastoralists using smartphones to generate and disseminate high-frequency market data through the micro-tasking approach.

In the crowdsourcing literature, the study showed that crowd workers engaged in micro-tasking on their livelihood activities could be incentivized by systematically providing feedback whose content is insights generated from the data they provide. Our results show that providing information on prices increases participation. Enhanced participation is further observed when additional information on the link between the data collected, and information feedback given is disclosed. In addition, the study demonstrated the effectiveness of a combination of monetary incentives with non-monetary incentives to increase participation in micro-tasking. While the results could be intuitive, findings from similar studies show a limited effect of information provision (commonly framed as feedback) on contributors' participation (Nisa *et al.,* 2019; Solano-Hermosilla *et al.,* 2022).

The results advance the sustainability debates on MIS, which have mostly been challenging in pastoral settings (Stuth *et al.,* 2006; Shiferaw *et al.,* 2011; Roba *et al.,* 2018). They demonstrate the value of market price information dissemination in enhancing the sustainability of collecting high-frequency data through micro-tasking. The information disseminated, however, needs to be scripted with sufficient clarity to relay the true connection with the data collection process. The study further provided evidence of the expanded application of micro-tasking from data collection to a viable dissemination option. This finding is consistent with the successful application of micro-tasking in the rapid assessment of the impacts of the COVID-19 pandemic on agricultural-based livelihoods (Adewopo *et al*., 2021; Chelanga *et al*., 2020) and their environment (Graham *et al*., 2021).

Effective leveraging of micro-tasking in pastoral markets could further be harnessed by improving the infrastructure. This will allow for micro-tasking in more markets operating in more remote production catchments. Further research to investigate the impact of the price information feedback provided on the production, marketing, and consumption decisions of pastoralists could be beneficial. It would also advance the packaging and use of information dissemination to improve the decision capacity of the pastoralists. It will also lay a foundation for inculcating intrinsically incentivized remote data sharing behaviors using digital platforms.

CHAPTER SEVEN

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

Livestock production plays an important role in the livelihoods of pastoral households. It is the main source of food- mainly from milk and meat, and income - through sales of live animals. As such, markets play a pivotal role in facilitating the process of offloading production surpluses and filling consumption deficits. Public and private sector investments aimed at creating functioning markets have not been successful for decades. This has partly been due to socio-environmental peculiarities and disproportionately low investments and limited knowledge of pastoral settings.

Over time, evidence of poor functioning pastoral markets and their implications on household welfare have been documented. While the insights and recommendations from these studies point to a wide array of innovations, establishing a robust MIS is cannot be underestimated. Therefore, the purpose of this study was to determine the effects of mobiles phones access on two key market concepts i.e., spatial market integration and household market participation. In addition, it provided insights into the potential of using mobile phones in enabling micro-tasking-based crowdsourcing to address the information scarcity gap.

The study was conducted in three dryland counties: Marsabit, Isiolo, and Samburu. Two sets of panel data; one generated through a crowdsourcing endeavor and another using conventional household surveys were used for analysis. The first panel generated through crowdsourcing comprised weekly price data for animals traded in ten livestock markets operating within the sampled counties. Ten contributors in each sampled market collected data using an open-source micro-tasking platform for 43 weeks (November 2019 to September 2020). This provided an input for answering two specific objectives of the study—the first: To determine the current level of market integration between dryland livestock markets of Kenya and the third objective of the study was to determine the impact of price information feedback as a complementary incentive on the participation of pastoralists in crowdsourcing dryland information. The first objective used crowdsourcing data to analyse spatial market integration between sampled markets in the study site. Data analysis entailed constructing market-level price trends using time-series graphs and cointegration analysis using the vector error correction model.

The third objective had two hypotheses: one focusing on the agility of the crowdsourcing platform and another on incentivizing contributor participation in micro-tasking. In the first hypothesis, the data generation process, and the data itself were used to demonstrate the rationale and application of crowdsourcing in tracking market information and other complementary indicators in the drylands. In the second hypothesis, two incentive regimes for motivating contributors' participation to provide data using the platform were tested. A DID identification strategy was used to analyse the data fitted on the panel data Tobit model.

The second panel comprised seven rounds of survey data collected at the household level from an original sample of 924 households beginning in 2009 to 2020. This data was used to analyse the effect of mobile phone access, measured by years of access (duration) and its influence on household market participation i.e., the second objective of the study. Data was fitted into an ordered Tobit model, that accounts for sequential household market participation decisions. The intensive margins were modeled using the ordered Probit model, which accounts for endogeneity, using the ERM framework. The extensive margins were also estimated separately for purchases and sales using OLS implemented under the ERM framework. This chapter presents the summary of the results, conclusions, and recommendations of the study.

7.2 Summary of Study Findings

The characteristics of the sampled markets show that they were mostly distributed within major towns and production catchments within the Moyale – Isiolo tarmac road and thus the same trading route. Only Lekuru market, which is in a different trading route, was sampled to test if integration could exist between markets that do not necessarily have trade with each other. The average market prices for goats were higher in markets located in major towns in the region and lower in those closer to pastoralist production catchments. Moyale market which doubles as a regional and border market had the highest mean goat prices across the period. The lowest prices were observed in Korr market, which is the smallest and located a few kilometres (60km) away from the tarmac road. The price trends obtained did not show peculiar seasonality. This implied that the above-normal weather conditions experienced in 2019 and 2020 increased forage availability despite the invasion by locusts. COVID-19 pandemic was also another exogenous shock occurring during the period. Prices in a few markets (Merille, Lekuru, and Acherspost) responded to the COVID-19 movement restrictions, with the shocks evening out after 3-4 weeks.

The unit-roots test using both ADF and PP tests confirmed the presence of stationarity in the first difference in all the market price series. The AIC was used to obtain the optimal lags to be included in cointegration and the autoregressive models. The Johansen cointegration test confirmed the presence of cointegration in more than one price series. As a result, the VECM framework was used to estimate the short and long-run causal price relationships. From this framework, the speed of price adjustment from price shocks was also estimated. Most markets exhibited high speed of adjustments into a long-run equilibrium implying low information asymmetry and market frictions.

Short-run causal relationships between markets operating along the same trading route were dominant. Markets along the Moyale-Isiolo trading route showed indications of efficient price transmission. This was despite other markets like Korr being located away from the Tarmac Road. It was notable that Isiolo market, which is the largest urban market in the region, prices were not significantly affected in the short run by prices in other sampled markets. It however causes significant short-run effects on prices of other markets (Merille and Korr) which are deemed to be important surplus markets in the region.

It was also evident that Moyale border market has significant short-run relationships with closer inland markets (Merille and Acherspost). Smaller markets (e.g., Korr), located off the tarmac roads, hardly transmit significant price signals. They mostly receive shocks from other larger markets in the region. Generally, the presence of short-run causal relationships between markets in the region provides evidence of increasing efficiency in information flow.

Long-run causal relationships between the regional terminal market (Isiolo) and other intermediate and feeder markets in pastoral settings exist. It is evident that both markets experience a regular flow of trade (Merille and Korr) and those that do not trade (e.g., Lekuru Market). This further indicates evidence of an efficient flow of price information such that traders can exploit possible arbitrage opportunities whenever they occur. It is also important to note that the pastoral border market prices have a weak long-run causal relationship with in-land regional markets. Furthermore, the relationship between perfectly placed inland markets (Isiolo and Acherspost) warrant further investigation. They exhibit weak long-run and short-run relationships despite being closest to each other, connected with tarmac, and having good communication networks.

At the household level, the study findings show that most pastoralists participate in markets as net sellers. They are net sellers of SR rather than LR. This means SR sales are more likely used to cover household recurrent consumption expenditure. In both cases, only a few are net buyers. It is also notable that the informal exchange of livestock continues, even for households that are in the autarky category of market participation. This shows that besides trade, informal exchanges between households play an important role in supporting livelihoods. Moreover, with the high percentages of non-trading pastoral households, it indicates that transaction costs, fixed or proportional, are still a deterrent to market participation of pastoral households. There is also a notable variation in dependence on livestock income by household settlement type. The study shows that partially sedentary and nomadic pastoralists have a high livestock income ratio compared to those fully settled implying that markets play an important role in facilitating sales.

Variation in the duration of access to mobile phones between pastoralists exists. Some pastoral households still have limited access to mobile phones. Duration of access increases as network coverage expands to new areas. The frequency of access has also increased, and currently, most pastoralists use mobile phones daily. An increase in duration and frequency of access means most pastoralists are more accustomed to using mobile phones in their economic activities i.e., in both production and marketing. Notably, access to mobile phones complements other traditional channels, predominantly "word of mouth", in searching market information from local sources. The study also shows that besides market price information, other information types like availability of forage, water, and security are crucial in enabling market access.

The panel regression models showed that changes in duration cause variation in both the likelihood and intensities of market participation. The effect varies in magnitude and direction depending on the households' distance to the main livestock market. An increase in duration for households located closer to markets causes transformation into market-oriented production—it causes an increase in quantities sold. However, with a duration exceeding three years, distant households reverse their trend from increasing to decreasing quantities of livestock sold. With evidence of demand for diverse market information types e.g., security enroute, water and forage, the decreasing sales by distant households show that access to mobile phones is not sufficient to break all these market access barriers. It is, therefore, likely that distant households transferred the digital dividends into unprecedented herd build-up through a reduction of sales.

At the pastoral individual level, the findings demonstrate how monetary and non-monetary incentives could be combined to encourage contributor participation in micro-tasking. The piece rate payment structure used in the first six weeks before introducing the treatments substantially motivated the contributors to participate in the activity. It was also an integral part of the incentive structures used in the first and second information treatments. Although this study does not compare monetary incentives with other possible extrinsic motivators, the results support the use of monetary incentives in real effort tasks. It further supports the feasibility of using piece rate payment structures in activities that have traditionally been rewarded with flat rate payment structures.

The objective here was to of test whether providing feedback in the form of insights generated from the data submitted by the contributors supported the value of feedback in evoking intrinsic motivation. It also demonstrated the importance of clarity in the process and content of the feedback. The contributors may have found value in the feedback provided in the first treatment. However, they may not have linked the quality of the information to their participation levels. While the increased participation could be attributed to the feedback reinforcing intrinsic motivation, it is also possible that it was filling market information gaps faced by the contributors and other pastoralists within their sphere of influence in the region. The finding shows that the provision of feedback to users of digital platforms to enhance utilization is crucial.

The additional results on the spillover effects of the information treatments could be interpreted as a benefit from contributors finding value in the information. There exists a close link between market activities and households because pastoralists depend on livestock and livestock markets for their livelihoods. For this reason, the value of shared information treatments is more likely to incentivise increased participation in household-level daily tasks. It then implies that the price information feedback was able to maximize the contributors' effort in both task categories. As such, contributor participation in micro-tasking could be incentivised by a subset of appealing tasks with an ability to spill over an equivalent level of effort to other complementary tasks in the same activity.

7.3 Conclusions of the Study

The findings from this study provide fundamental insights into the current state of market integration in pastoral markets. It shows that a higher proportion of price variation in the intermediate markets in the region is due to its shocks while similar variation in smaller markets originates from the larger markets. As such, intermediate markets are senders of price information while the feeder markets are receivers of price information. This indicates a unidirectional price transmission i.e., from deficit markets to surplus markets. It, therefore, suggests that more investments, beyond communication technologies, are needed to reduce market frictions in feeder markets operating close to production catchment areas. This could include further investments in physical infrastructure like roads, to increase market access by pastoralists in production catchments.

An increase in the duration of access to mobile phones increases market participation for households living near the main regional market. Distant households living beyond 115 kilometres from the main market reduce the volumes of livestock traded as the duration of access to mobile phones increases. To support market-oriented production, and the resultant market participation, more investments that increase consistent availability of water, forage, and security would facilitate inclusive increased market access. Similarly, strengthening complementary efforts that support herd build-up could also be beneficial. This could include recent attempts to financialise risk markets through novel index-based livestock insurance, aimed at reducing common losses due to drought. In addition, further improvement of market and road infrastructure near production catchments would minimise the reliance on accessing regional markets for better prices. It also reduces the effects of barriers currently difficult to break through access to mobile phones. With the duration of mobile phones increasing over the unforeseeable future, effecting the investments would provide the necessary environment for expansion and re-orientation of market participation motives for pastoralists.

The field experiment on incentivising pastoral contributors to microtask provides insights that feed broadly and specifically into both the crowdsourcing and the agricultural information systems literature. Broadly speaking, the accomplishment of micro-tasking in pastoral areas of Kenya is a key indicator of the increasing feasibility of using digital systems in other rural and remote settings whose infrastructure is evolving and demand for high-frequency data is steadily increasing. In more specific lenses, MISs targeting pastoral settings should leverage the growing number of pastoralists using smartphones to generate and disseminate high-frequency market data. This approach could also extend to other indicators relevant to the livelihoods of pastoralists e.g., rangeland, household welfare (nutrition, consumption, income, etc.), and production indicators.

In the crowdsourcing literature, the study showed that crowd workers engaged in micro-tasking on their livelihood activities could be incentivized by systematically providing feedback whose content is insights generated from the data they provide. The results show that providing information on prices increases participation. Enhanced participation is further observed when additional information on the link between the data collected, and information feedback given is disclosed. In addition, the study demonstrated the effectiveness of a combination of monetary incentives with non-monetary incentives to increase participation in micro-tasking.

The results advance the sustainability debates on MIS, which have mostly been challenging in pastoral settings. They demonstrate the value of market price information dissemination in enhancing the sustainability of collecting high-frequency data through micro-tasking. The information disseminated, however, needs to be scripted with sufficient clarity to relay the true connection with the data collection process. The study further provided evidence of the expanded application of micro-tasking from data collection to dissemination. It also shows that multiple indicators of interest in the drylands could be consistently tracked using a mobile phone-based micro-tasking approach.

7.4 Recommendations of the Study

The study draws a few recommendations based on the conclusions made in each concept studied. From the market integration results, this study recommends expansion of physical infrastructure to connect more markets located near production comments. This will increase access by both distant traders and remote pastoralists. It is also imperative to boost market information density to producers supplying these markets so that their reserve prices and bargaining power could be improved. This could be done through efficient high-frequency data gathering innovations like crowdsourcing and disseminating information generated through mobile phones and existing traditional channels. To further reduce transaction costs and boost producer response to prices, collective action efforts, through marketing and production groups would boast effective price transmission.

To support market-oriented production, more investments beyond increasing access to mobile phone technologies are crucial. Increasing consistent availability of water, forage, and security would facilitate inclusive increased market access. Similarly, strengthening complementary efforts that support herd build-up could also be beneficial. This could include recent attempts to financialise risk markets through novel index-based livestock insurance. With the duration of mobile phones increasing in the unforeseeable future, implementing the investments would provide the necessary environment for expansion and re-orientation of market participation motives for rural households.

Crowdsourcing is a feasible option for overcoming many of the challenges and costs of data collection faced when using conventional survey methods. It is even more useful when tracking dynamic indicators from communities with mobile-phone network connectivity but living in distant locations. The study has demonstrated that micro-tasking could be used to collect accurate high-frequency data on various dynamic indicators that have proven difficult to collect at a high frequency using conventional field survey methods. Effective leveraging of micro-tasking in pastoral markets could further be harnessed by improving the access to smartphones and strong network coverage. This will not only allow for micro-tasking in more markets domiciled in more remote production catchments but also provide a large pool of potential contributors.

Based on the conclusion drawn from the engagement of pastoral contributors in providing market and household data, the study recommends changes in the composition of the data monitors currently engaged by development agencies and the rewards used to compensate for their efforts. The current efforts mostly engage selected experts from target communities to monitor production, environmental, and market indicators. This study recommends that the data monitors could include non-experts from the communities, with knowledge of the context, and how to use smartphones. This would improve the representativeness of the data generated and minimize the risks of missing data commonly caused by the attrition of the few engaged monitors. The study also suggests re-packaging of incentives to include both monetary and non-monetary incentives. The non-monetary incentives could be composed of information packages generated from data submitted and/or other complementary sources. Such re-organization would facilitate the sustainability of information systems targeting rural communities.

7.5 Limitations of the Study

Only price data was used in the study of market integration. While it was the most feasible option, the study is limited in quantifying the effects of important variables like trade flows and the actual transaction costs incurred in trading between the sampled markets. Similarly, most of the analysis used data linked to small ruminants (goats and sheep). This was based on the availability and consistency of the data. However, the inference of the study findings could have benefited more if an equivalent amount of data on large ruminants (Cattle and Camels) would be available.

The micro-tasking experiment was conducted for only 19 weeks. It could have continued for longer if it were not for the effects of COVID-19 movement restrictions on the functioning of markets. With this relatively short period, the study could not provide treatment to the original control. This would lead to having each experimental arm have exposure to the treatment as suggested in recent literature. This could have permitted the use of a two-way fixed effects framework rather than the conventional DID approach and thus allowing for in-depth analysis.

7.6 Areas for Future Research

This study demonstrated the potential of using micro-tasking-based crowdsourcing in generating agricultural market price data in remote locations. Using a similar framework, future studies should explore designs that capture transaction costs and actual livestock trade flow to provide more insights into the state of market integration in the region. This will also enable researchers to use advanced regime-switching methods in analysing spatial market integration in remote agricultural settings. These methods have been difficult to use because of a lack of data.

The findings from this study also showed that market information could incentivize increased participation in micro-tasking-based crowdsourcing. This implied that pastoralists value precise market information shared on time through digital platforms. Further research to investigate the impact of the price information feedback provided on the production, marketing, and consumption decisions of pastoralists could be beneficial. It would advance the packaging and use of information dissemination to improve the decision capacity of the pastoralists. It would also demonstrate the relevance of high-frequency information dissemination on the livelihoods of households in remote locations. Moreover, policy debates and frameworks would be guided by accurate and sustainable information access.

Duration of access to mobile phones influences both the categorical and continuous market participation outcome. The findings from this study show that pastoralists uniquely change their market participation behaviors while maneuvering other market access challenges like security, water, and forage availability. First, further research on the effect of the duration of access to mobile phones on the dynamics of household welfare indicators would be crucial. It would help unpack the challenges faced by late adopters of technology and provide the necessary mechanism for improving their welfare. Secondly, the market participation behaviors of distant households warrant more investigations. This would help them to understand the interconnection between market access challenges they face, and the feasible solutions needed. This could focus on the interaction between collective action and access to digital market information sources.

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APPENDICES

Appendix I: Additional results tables and graphs

Appendix IA: Additional Information on Market Integration

Table 1A: Augmented Engle-Granger test for cointegration

	Test statistic	1% Critical Value	5% Critical value	10% Critical Value
Z(t)	-5.748	-5.922	-5.14	-4.757

Notes: Number of lags = 1; N (1st Step) = 41; N(Test) = 39; Critical values from Mackinnon (1990, 2010)

Appendix IB: Additional Information on Market Participation

Table BI: Summary of livestock stock and mobile phone access variable disaggregated by market participation category

Market Participation	Autarky (n=2310)		Net buyers (n=455)		Net sellers (n=3604)	
	Mean	SD	Mean	SD	Mean	SD
Informal livestock exchanges						
Offtake volumes	0.2	1.407	0.261	0.967	0.446	1.7
Intake volumes	0.337	1.184	1.024	2.607	0.789	2.349
Livestock Stock						
Livestock herded	6.65	13.779	13.858	22.685	20.834	26.634
Livestock owned	5.388	10.263	11.938	21.321	17.377	20.614
Livestock traded (TLUs)						
Livestock sold	0.008	0.09	0.429	1.281	2.024	3.76
Livestock purchased	0.008	0.09	1.941	3.623	0.1	1.138
Livestock income ratio	0.237	0.403	0.325	0.407	0.756	0.336
Mobile phone access (years)						
Duration by any member	3.065	4.508	2.431	4.208	0.961	2.461
Duration by head	*2.368*	*4.033*	*1.927*	*3.807*	*0.696*	*2.11*

Source: Household survey data 2009 – 2020

Table BII: Description of key components of the outcome and treatment variable disaggregated by household settlement category.

	Fully sedentary (n=2361)		Nomadic (n=142)		Partially sedentary (n=3862)	
Variables	Mean	SD	Mean	Sd	Mean	SD
Informal livestock exchange						
Offtake volumes	0.168	0.966	0.169	0.759	0.457	1.841
Intake volumes	0.343	1.078	0.582	1.416	0.826	2.45
Livestock Stock						
Livestock herded	8.26	18.457	26.436	30.747	19.024	24.859
Livestock owned	6.854	15.092	22.109	24.909	15.838	19.223
Livestock traded (TLUs)						
Livestock sold	0.691	2.23	1.893	4.578	1.451	3.301
Livestock purchased	0.216	1.159	0.208	0.884	0.187	1.515
Livestock income ratio	0.299	0.401	0.79	0.369	0.674	0.408
Mobile phone access						
Duration by any member	2.763	4.564	1	2.18	1.29	2.791
Duration by head	2.299	4.152	0.5	1.675	0.869	2.28

Source: Household survey data 2009-2020

Table BIII**:** Description of the most common market information sources and channels used

Market information sources	Market information channels				
	Word of mouth	Mobile phones	Personal account	Radio	Total
Local FM radio	3.35	8.76	1.85	100.00	6.34
Neighbour	43.53	13.14	55.56	0.00	38.48
Manyatta broker	31.96	24.09	22.22	0.00	29.38
Local market broker	17.81	24.09	16.67	0.00	18.32
External traders	0.61	0.73	0.00	0.00	0.58
Relatives living near markets	1.52	2.92	0.00	0.00	1.61
None	1.22	26.28	3.70	0.00	5.30
Total (column percentages)	100.00	100.00	100.00	100.00	100.00

Source: 2020 round 7 household survey. Manyatta is an equivalent of a village.

Table B.IV: Description of information channels and duration of mobile phone access

Information channels	Duration of access to mobile phones		
	Mean	Std. Dev.	Freq.
Mobile phones	8.102	6.042	137
Personal account	6.074	4.215	54
Word of mouth	5.820	4.740	657
Radio	5.800	2.587	20
Total	6.196	4.964	868

Source: Household survey data 2020 (round 7). Households with a high duration of access to mobile phones use mobile phones as the most important channel.

Table BV**:** Regression results of endogenous and instrumental variable

Duration of access to mobile phones (years)	Unconditional OLS		Conditional OLS	
	Coeff.	SE	Coeff	SE
Duration of network connectivity (years)	0.603***	0.006	0.275***	0.014
Constant	-0.31	0.086	9.174	2.683
Controls (including time dummies)	NO		YES	
Overall r-squared	0.299		0.365	
Chi-square	9802.799**		11929.05**	
R-squared between	0.153		0.204	
R-squared within	0.65		0.701	
Number of observations	6369		5900	

Source: Marsabit panel data 2009-2020.

Note: *** p<.01, ** p<.05, * p<.1. Standard errors are clustered at the household level. The significance of the coefficients of the instrument in both regressions indicates the validity of the instrument.

Table BVI**:** Panel data condition and non-condition Tobit regression results

	Unconditional panel Tobit		Conditional panel Tobit	
Market Participation	Coeff.	SE.	Coeff.	SE
Duration of mobile phone access (years)	-1.98***	0.489	-2.219***	0.673
Distance to main livestock market (log)	-2.165***	0.473	-0.775***	0.273
Duration* Distance to main livestock market	0.328***	0.085	0.384***	0.118
Controls (Including time dummies)	NO		YES	
Constant	14.084***	2.77	2.979***	1.732
Sigma_u	2.077***	0.732	1.455	0.737
Sigma_e	3.262***	0.619	3.112	0.479
Log-likelihood	-17204.915		-15476.65	
Likelihood ratio χ^2	36.463***		653.15***	
Number of observations	6369		5900	

Note: *** p<.01, ** p<.05, * p<.1. SE= Bootstrap standard errors. The non-conditional regression uses the full sample (1064 clusters in hhid) since there is a low likelihood of missing data. The conditional regression has controls with missing data hence lowering the sample size (1007 clusters in hhid).

Appendix IC: Additional Information on KAZNET open-source platform & Contributor participation

Table C1 and C.2 show the results of the panel Tobit model estimated using the treatment covariates only i.e., without including other controls for direct and spillover effects, respectively. Ideally, if the effect of the treatment were stable, then the coefficients should be similar in magnitude and direction.

Table C1**:** Unconditional Tobit regression direct effects results

Participation; Average weekly submissions	Average effect on Latent variable	Marginal effects	
		Censored sample	Truncated sample
Group effect	-1.123	0.235	0.167
	(0.901)	(0.582)	(0.413)
Treatment period one	1.026**		
	(0.479)		
Treatment period two	0.073		
	(0.651)		
Price information	0.155	0.671***	0.473***
	(0.823)	(0.262)	(0.184)
Price information +script	3.582***	1.360***	0.962***
	(0.983)	(0.416)	(0.299)
Sigma_u	3.587***		
	(0.420)		
Sigma_e	3.763***		
	(0.216)		
rho	0.4760		
	(0.061)		
Number of observations (N*T)	1197	1197	1197

*** p<0.01, ** p<0.05, * p<0.1. Standard errors (Bootstrap) are provided in parentheses.

Table C2: Tobit regression unconditional spillover effects results

Participation; Sum weekly submissions	Average effect on Latent variable	Marginal effects	
		Censored sample	Truncated sample
Group effect	0.310	0.530	0.379
	(.692)	(0.3196)	(0.230)
Treatment period one	0.133		
	(0.331)		
Treatment period two	0.504		
	(0.472)		
Price information	0.346	0.166	0.120
	(0.527)	(0.145)	(0.104)
Price information +script	1.448**	0.552***	0.391***
	(0.733)	(0.212)	(0.152)
Sigma_u	2.289***		
	(0.195)		
Sigma_e	2.282***		
	(0.150)		
Number of observations (N*T)	1140		
Weekly dummies	yes		

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard errors (Bootstrap)are provided in parentheses.

The OLS and Poisson estimates shown in Table C.1 and **Table** C.2 have a mix of similarities and differences with those from the Tobit regression in Tables 6.2 and 6.3. The treatment coefficients have the same direction in effect but varying magnitudes. Poisson treatment estimates are more dissimilar as none is significant. However, other controls, like education level and group membership status of the contributors, are consistent in magnitude and direction with estimates in Tables 6.2 and 6.3. This is also true for the OLS estimates. The OLS estimate for the first treatment is positive and significant for the direct effect. Overall, there is no alarming variation in the coefficients across different specifications—there is a general agreement in the direction of the treatment effects. Therefore, it is reasonable to argue that the results are robust.

Table C3: Direct unconditional and conditional OLS and Poisson regression results

Participation; Average weekly submissions	Unconditional OLS	Conditional OLS	Conditional Poisson	Unconditional Poisson
Group effect	-.276	.28	-.107	.038
	(.482)	(.631)	(.188)	(.212)
Treatment period one	.818***	.818***	.262***	.262***
	(.306)	(.307)	(.092)	(.092)
Treatment period two	.321	.321	.111	.111
	(.345)	(.347)	(.116)	(.116)
Price information	.181	.181	.079	.079
	(.501)	(.504)	(.155)	(.155)
Price information +script	2.202***	2.202***	.596***	.596***
	(.663)	(.666)	(.196)	(.196)
Market connectivity		.721		.217
		(.532)		(.185)
Group membership status		1.742***		.634***
		(.492)		(.218)
Gender of contributor		.293		.018
		(.556)		(.228)
Education level		-.986*		-.255
		(.572)		(.232)
Distance to market		-.044		-.017*
		(.028)		(.009)
Digital survey experience		-.103		-.046
		(.549)		(.222)
Age of contributor		.038		.016
		(.032)		(.014)
Contributor TLU owned		.009		.004
		(.006)		(.003)
Main occupation				
Casual Labor		-2.618***		-.848***
		(.658)		(.257)
Govt Employee		.14		.004
		(.814)		(.255)
Livestock Trader		-.434		-.337
		(.767)		(.414)
Market agent		-.989		-.237
		(1.191)		(.409)
Shop keeper		-1.63*		-.725*
		(.871)		(.438)
lnalpha			-.367	-.589
			(4.787)	(4.744)
Weekly dummies	yes	yes	yes	yes
Observations	1197	1197	1197	1197

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors (Clustered at contributor level) are provided in parentheses.

Table C4: Spillover unconditional and conditional OLS and Poisson regression results

Participation; Sum weekly submissions	Unconditional OLS	Conditional OLS	Conditional Poisson	Unconditional Poisson
Group effect	.311	.745*	.276	.794*
	(.317)	(.413)	(.274)	(.41)
Treatment period one	.093	.093	.09	.09
	(.203)	(.204)	(.194)	(.194)
Treatment period two	.056	.056	.055	.055
	(.267)	(.269)	(.261)	(.261)
Price information	.236	.236	.136	.136
	(.28)	(.281)	(.232)	(.232)
Price information +script	.695*	.695*	.403	.403
	(.393)	(.395)	(.315)	(.315)
Market connectivity		.262		.179
		(.331)		(.28)
Group membership status		.545*		.444*
		(.326)		(.257)
Gender of contributor		-.069		.004
		(.375)		(.279)
Education level		-.844**		-.893**
		(.367)		(.408)
Digital survey experience		.365		.572
		(.389)		(.356)
Age of contributor		.018		.006
		(.029)		(.016)
Contributor TLU owned		-.004		-.002
		(.004)		(.003)
Main occupation				
Casual Labor		-.361		-.279
		(.519)		(.298)
Govt Employee		.702		.662
		(.721)		(.554)
Livestock Trader		.23		.405
		(.467)		(.563)
Market agent		.325		.873
		(.79)		(.725)
Shop keeper		.446		.331
		(.603)		(.356)
lnalpha			-.105	-.263
			(2.717)	(2.57)
Weekly dummies	yes	yes	yes	yes
Observations	1140	1140	1140	1140

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors (Clustered at contributor level) are provided in parentheses.

One other dimension of looking at the robustness of the results is by averaging the submissions per treatment period. Three data points are obtained for each contributor, i.e., one average value for each period's weekly submissions. This way, the effect of the treatments on the participation of the contributors is assumed to be based on the traditional DID estimation procedure. Both conditional and unconditional OLS estimates with fixed effects are similar in magnitude and direction.

Table C5: Direct unconditional OLS and Tobit regression results for treatments estimated at the period levels

Participation; Sum weekly submissions	OLS	Tobit Model		
	Unconditional	Average effect on Latent variable	Marginal effects	
			Censored sample	Truncated sample
Group effect		-.567	0.276	0.233
		(.679)	(0.603)	(0.462)
Treatment period one	.818**	.977***		
	(.308)	(.367)		
Treatment period two	.321	.343		
	(.348)	(.405)		
Price information	.181	.023	0.803***	0.215***
	(.505)	(.69)	(0.288)	(0.591)
Price information +script	2.202***	2.506**	1.482***	1.137***
	(.669)	(1.014)	(0.431)	(0.346)
Sigma_u		2.368***		
		(.247)		
Sigma_e		1.986***		
		(.168)		
Number of observations	189	189	189	189
	.268			
R-squared				

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors are clustered at the contributor level for the OLS estimates and Bootstrap for the Tobit estimates, which are provided in parentheses.

Appendix II Questionnaires.

Two different tools were used to obtain data necessary to analyse the objectives of the study. The data is contained in the following links:

a. For market integration and crowdsourcing, the data in the following link were used.

   https://kaznet.ona.io/kaznet/99377/454932.

b. For market participation:

   https://ccafs.cgiar.org/sites/default/files/files/IBLI%20Borena%20Household%20Survey%20Codebook%20-%20September%2020%202014.pdf.