5-2012

Access to Information in the Developing World: The Role of Mobile Telephony in Economic Development

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An Honors Thesis

Presented to

The Faculty of the Department of Economics
Bates College

in partial fulfillment of the requirements for the
Degree of Bachelor of Arts

by

Michael B Sagan
Lewiston, Maine
March 23rd 2012

Abstract

Classical theory suggests that economies operate efficiently when agents have open and symmetric access to market information such as the price, quality, and availability of goods and services. Emerging economies often lack the infrastructure and institutional framework necessary to facilitate this fluid transmission of information, and are subsequently defined by informational divides that sustain systemic structural impediments to development. The recent proliferation of mobile telephone services in the developing world, however, has created new possibilities for information-sharing among the globe's poorest populations, and has introduced the potential for development that is both economically sustainable and inherently "bottom up."

This paper considers the role of mobile telephony for development through an empirical examination of agricultural markets in one of the world's poorest countries—Mozambique. Using established methods of analysis in conjunction with a novel geospatial approach, we find that while the introduction of cellular technology has a discernible impact on agricultural price behavior in our sample, overall the estimated effect of mobiles falls short of our expectations. This study therefore draws upon an alternative theory on price dispersion and connects it with the current empirical research on mobiles phones for development. In total, we conclude that while mobiles are an influential force in Mozambique's staple food markets, additional constraints such as trade discontinuities between markets are the primary source of persistent price dispersion and inefficiency.

Acknowledgments

I would like to express my thanks and sincere gratitude to those who have provided me with guidance and support throughout the writing of this thesis.

I wish to thank my friends and family for their enduring support and encouragement—to my parents for pushing me to work hard and to remain passionate about my curiosities, to my older sister Katie for being an inspiring advocate for development and social responsibility, to my youngest sister Emma, for keeping the bar “set high” for the rest of us, to my friends and roommates for being there with words of encouragement, and finally to Dean Holly Gurney, who was always there guide me through difficult times and offer advice throughout my college career.

This thesis would not have been possible without the generosity of several sources that have provided me data. First, I would like to thank Professor Jenny Aker of Tufts University for sharing data on mobile phone networks in Mozambique. Second, I owe a debt of gratitude to Cynthia Donovan of Michigan State University as well as the Mozambique Ministry of Agriculture and *SIMA* for providing me with agricultural price data. Third, I would like to thank Mathieu Duvall and William Ash of the Bates College Imaging Center for technical assistance. Finally, I would like to thank John Panzer and Vasco Molini of the World Bank for providing me with proprietary GIS data.

Finally, I would like to thank my advisor, Michael Murray. There were many times throughout the course of writing this thesis where I felt lost, confused, frustrated, sad, agitated, defeated, or exhausted (sometimes all at the same time) and without fail, Professor Murray would manage to clarify a concept, offer encouragement, or suggest a strategy that would raise my spirits and reconstitute my passion for this research. He is an inspiring professor and an excellent teacher, and I will remain forever privileged to have been his student.

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Introduction

Since the introduction of cell phones nearly two decades ago, mobile telephony has experienced near exponential growth and widespread adoption throughout the world. Living in the United States, we observe on a daily basis the impact that mobiles have on our lives—the ability to call friends, coordinate with colleagues, and access the seemingly infinite volume of information available on the Internet has become integrated into our normal routines. A recent survey by the Pew Research Center now indicates 8 out of every 10 adults in the United States owns a cell phone, and furthermore that 49% of Americans consider their mobile phone to be a "necessity" rather than a luxury—a truly remarkable achievement for a device that didn't exist just a few decades ago (Taylor et al. 2009). As mobile technologies are further refined and usage becomes even more prevalent, the importance of the cell phone will only continue to build as economies become increasingly technology oriented.

This widespread adoption of mobile technology is not confined to the world's wealthier nations. Figure 1, for instance, vividly illustrates the incredible phenomenon seen throughout the previous decade whereby developing nations are absorbing mobile technology on an unprecedented and exponential scale.

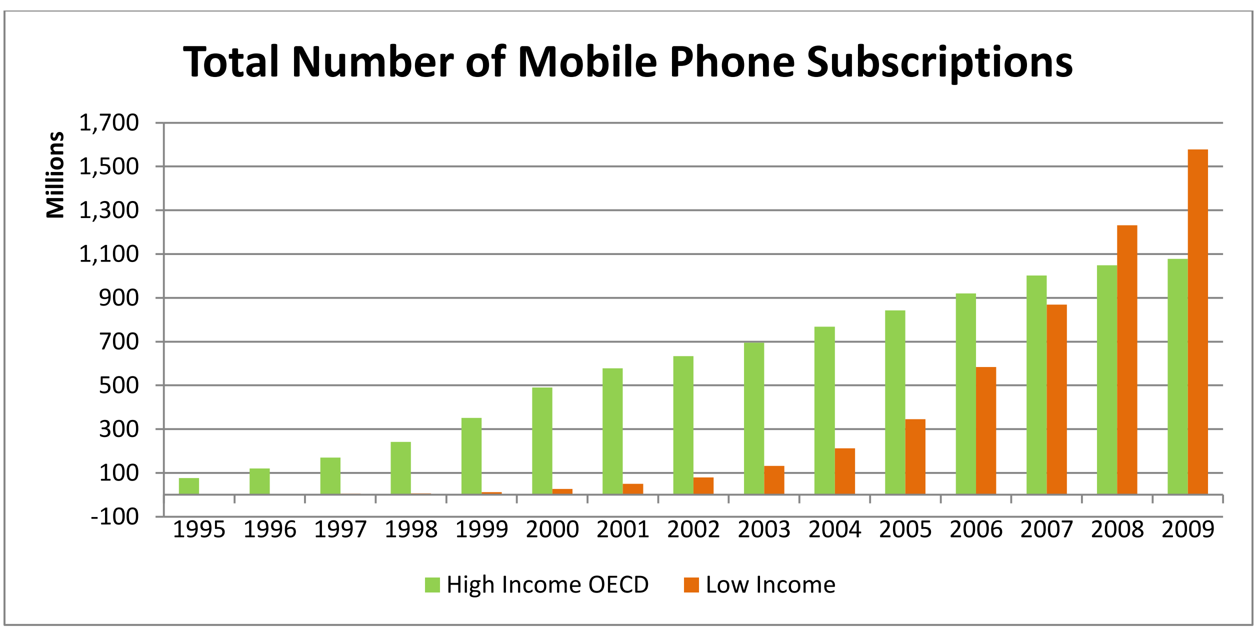


Figure 1. Source ITU 2011.

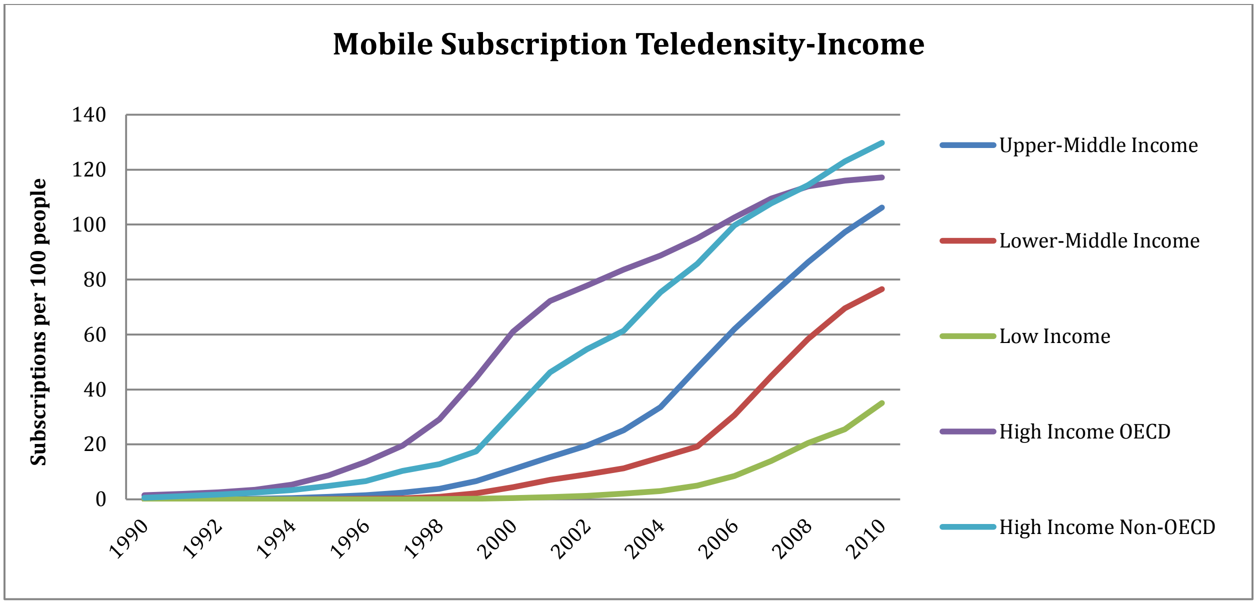


Figure 2. Source ITU 2010.

What is truly remarkable, however, is how robust this growth is even in regions where the average per capita income is just a small fraction of that of more developed nations. This phenomenon is indeed striking and points to the fact that the potential gains associated with cell phone use are large enough to warrant investment by some of the world's poorest populations.

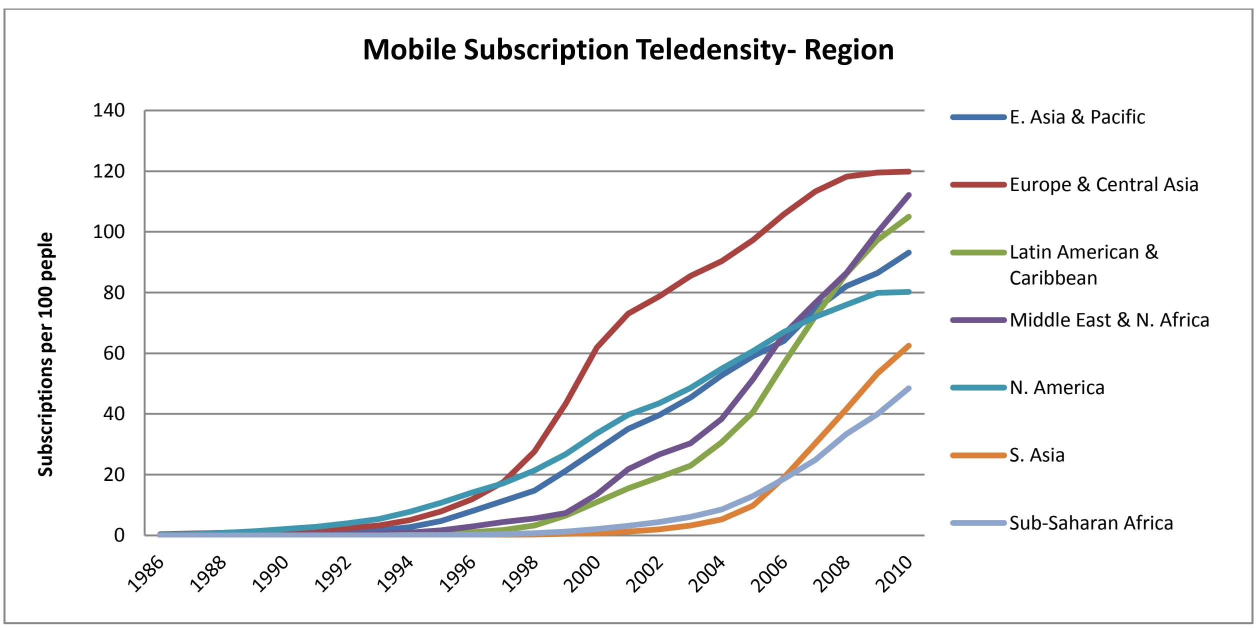


Figure 3. Source ITU 2010.

The recent trends presented in these graphs are hard to refute, and have coordinately attracted considerable attention from the development community. What is it exactly that is spurring the high levels of demand for mobiles phones, and through what channels—if any—are these new technologies reshaping the social, political, cultural, and economic landscapes of the developing world?

These questions form the central focus of the current study. As the digital age continues to evolve and information & communications technology (ICT) becomes more entrenched in the global economy, the role of ICT—and specifically *mobile* ICT—will become a progressively more important aspect of future development strategies. Indeed as teledensity increases in the developing world, the impact these devices have on economic outcomes will become increasingly pronounced, and the overall shift from "luxury" to "necessity" will be realized.

The rest of this paper is organized as follows. Section I outlines a review of the relevant literature, and draws broadly from previous studies on market theory, network economics, consumer search theory, and development economics. Section II provides background information on Mozambique, and likewise provides a description of the data and our empirical strategy. Section III presents the structure and findings of our empirical analysis, and Section IV concludes. Additional information can be found within the appendices as cited within the text.

Section I—Review of the Literature

The field of development economics, whether implicitly or explicitly, centers on growth theory. That is, understanding how markets develop, what factors hinder or enable that development, and what conditions, if any, will lead to a convergence among economies. While the exact nature of growth theory is hotly disputed, all models currently debated within the literature—be it classical specifications or the more contemporary endogenous growth models—agree on the necessity of "technological change" as a determinant of long-run economic growth.

Macroeconomic growth theory, however, frequently takes a "black box" approach to technological change, and often treats all efficiency-enhancing technologies, at least at an abstract level, as equal. Indeed, with a few notable exceptions,[1] growth theory does not richly discuss the specific components of technological change, but rather considers innovation in more generalist terms. While this may suffice when conducting large cross-country studies on economic development, it fails to provide pragmatic solutions for how technology can be harnessed to address issues of underdevelopment in the third world.

As such, the primary interest of this paper—and indeed the central research question of this study—is understanding how one particular technology—mobile phones—can impact market outcomes in emerging economies. The current literature regarding mobile telephony in the developing world is immense, drawing from multiple disciplines including anthropology, political science, sociology, as well as economics. While these perspectives are undoubtedly important for understanding the role of mobile phones across a range of cultures and political systems, the current study is limited to the areas of the literature that most directly address the quantitative aspect of the research question. These areas include classical market theory in the context of LDCs, theoretical studies on information and transaction costs in emerging markets and the subsequent role of telecommunications, and conclude with micro-econometric studies that measure the impact of mobile telephony on the markets in question.

It should be noted, however, that the omitted areas of the literature mentioned above offer an invaluable perspective on mobile telephones as an economic, social, and cultural phenomenon. This paper does not reject this complementary research, rather we maintain a quantitative focus

[1] Several studies do make attempts to model the nature of technological change. Basu and Weil (1996), for instance posit that technologies differ according to their "capital intensity" and hence diffusion of new innovation will be a function of its applicability to a particular economy while other work, for example Foster and Rosenzweig (1996) and Mankiw, Romer, and Weil (1992) show that education has positive impacts on output growth. The literature regarding specific technological interventions, however, remains sparse.

that is consistent with the spirit of economic analysis, and remain fully cognizant that mobile phones have additional consequences—both positive and negative—for other areas of daily life.

The Problem

In a basic theoretical sense, a market functions as a massive coordination system that generates "efficient" allocations of goods and services based upon the supply and demand conditions communicated through price behavior (Eggleston, Jensen, and Zeckhauser 2002; R Jensen 2007, 2-4). Indeed classical market theory stipulates the conditions necessary for this process—seminal work by Stigler (1961) and Akerloff (1970), for example, stress the importance of low-cost and "perfect information," while work by Stigliz (1979) espouses the "law of one price" as essential for generating efficient outcomes.

Shifting to the context of developing economies, emerging markets are typically characterized by conditions and institutions that run counter to these classical assumptions. Foremost of these are that LDCs often lack basic infrastructure—low telephone hardline penetration rates and inadequate roadways and public transportation often mean that travel is expensive, time consuming, and potentially dangerous, while at the same time the costs of accessing broader markets are prohibitively high for many individuals (see, for example, Eggleston (2002), Aker (2008 & 2010), Aker and Mbiti (2010), Overa (2006), and others). In an early cross-discipline study, Geertz (1979) finds that information shortages in rural village markets cause participants to devote a large amount of time and effort towards building and maintaining insular trade circles, and likewise result in the emergence of "clientelization." More current studies find similar trends among developing nations—Overa (2006) for example, finds that information asymmetries in Ghanaian cloth markets cause transaction costs to increase dramatically, forcing traders to rely on extra-market institutions such as trade cooperatives or intermediaries which inhibit access to broader markets. Similarly, Jagun, Heeks, & Whalley (2008) find that informational challenges "reduce the chances that business and trade will emerge…keep supply chains localized and intermediated…[and] make trade within those supply chains slow, costly, and risky."

The current state of emerging economies in turn generates outcomes that are in conflict with the basic market tenets outlined above—Aker (2008 and 2010), Badiane & Shively (1998), Jensen (2007), and Eggleston et al. (2002), for example, find that price dispersion for homogenous goods is higher in markets that lack telecommunications infrastructure (i.e. where information is costly), a phenomenon that is in direct violation of the "law of one price." Further theoretical study, for example by North (1995), postulates that the persistence of market failures and externalities will in turn force institutions to emerge that allow economic activity to take place despite these failures. Thus these patterns of localization, "clientelization," and intermediaries will continue to form in the void created by market failures, and the negative outcomes they produce will remain persistent.

While the issues that plague developing economies are as diverse as their respective social, cultural, and geographical underpinnings, the evidence is clear that information failures are pervasive in LDCs worldwide. When one considers both the importance of information for proper market function as well as the current state of LDCs, the disparity that exists becomes clear and points to the need for an intervention that can directly address these information gaps.

Why Cell Phones?

The potential of telecommunications for development has attracted considerable attention by economists. Early work by Leff (1984), for instance, shows that the introduction of telecommunications to developing countries "sharply reduces the costs of transmitting information over space and time" allowing for more optimal organizational structures to emerge (p.257). This improved availability of information in turn creates a ripple effect throughout the entire economy—both Leff (1984) and Norton (1992), for instance, show that lowering transaction costs through enhanced telecommunications infrastructure has the external effect of "making other institutions more efficient," thus promoting overall economic welfare. Norton (1992) builds upon Leff by finding empirical evidence that "low telecommunications infrastructure is one reason why some parts of the world have not developed," and posits that the positive externalities associated with increased communications technology have gone unrecognized, arguing further that ICT should be considered a primary policy tool going forward.

As technology advanced from landline- to mobile-based telephony, the value of cell phones to developing nations solidified. Empirical studies, for example by Waverman et al. (2001), Torero et al. (2003), Aker (2008 & 2010), Aker & Mbiti (2010), Must et al., and others, find that not only does increased *mobile* phone penetration lower transaction and search related costs, but the portability of cellular phones carries with it the added benefit of increasing the velocity with which information can be exchanged. These studies show that the theoretical basis for telecommunications technology is indeed valid when subjected to further empirical scrutiny, and that the shift from landline to mobile technologies further reduces transaction costs and increases the volume of and demand for information.

While the above discussion enforces the theoretical basis of mobile phones for development strategies, there are several other considerations that reinforce these findings. Research by Waverman et al. (2001), Chiu et al. (2008), as well as several policy papers by wireless carriers (see, for example, Vodafone 2005) shows that the relatively low costs associated with mobile phone rollout make implementation an obtainable development goal. Furthermore, the decentralized nature of cell phones promotes development that is inherently "bottom up." In his narrative on mobile telephony in Bangladesh, Sullivan (2007), for example, recounts how cell phones are empowering the poor—especially women—to engage in market activity that was previously unavailable to them. This potential for "bottom up," decentralized, private-sector development has in turn attracted the attention of policy arenas worldwide, whereby government organizations are beginning to look seriously at mobile telephony as a component of their respective development strategies (see, for example, Pedrelli 2001).

While current research has shown how mobile telephony will reshape the dynamics of search and transaction costs, a separate strand of literature focuses on how the near exponential increase in cell phone adoption has spawned additional mobile applications that generate positive externalities on their respective markets. Baliamoune-Lutz (2003) for instance, shows that more cell phone subscriptions within a country correspond to higher levels of political freedom and agency, while Sullivan (2007) finds that increased access to information creates new job opportunities and higher wage potentials. In addition, mobile applications are now introducing new possibilities for developing economies—organizations such as Satellife use mobile phones to track rural healthcare issues, while Aker & Mbiti (2010) discuss programs that enforce literacy through SMS messaging. The most intriguing new program to emerge from mobile technology, however, comes in the form of mobile banking. Studies by Jack & Suri (2011), Hughes and Susie (2007), Must & Ludwieg (2010), as well as several Vodafone policy papers comment on this phenomenon, whereby the ability to transfer money via SMS messaging (such as with the M-PESA program in Kenya) is streamlining transactions and extending banking services to populations that were previously without access to formal financial institutions.

The literature in the previous section outlines the structural problems that exist in developing markets due to information gaps, and finds that costly information in turn inhibits the efficient functioning of market systems. In response, there has been an emerging field of research on the use of mobile telephony to combat issues of information gaps in the developing world.

While an analysis of cell phones is admittedly a narrow subject within the broad realm of development policies, the classical theory on the importance of information, along with the findings put forth by current studies on the mobile phone usage, suggest that mobile phones will be an integral part of the development process going forward, and is worthy of in-depth analysis. Furthermore, mobile telephony is shown to have additional considerations that make it an intriguing and viable instrument for development policies. That is, while low fixed-costs of implementation and interest from private sector providers make mobile telephony *feasible*, the decreased transaction costs and increased access to information, the "bottom-up" nature of development, and the spillover effects generated by increased access to information make mobile telephony *appealing* from both a development and policy standpoint.

This study builds upon the current microeconomic literature by employing a quantitative analysis of agricultural price behavior in one of the world's poorest countries, Mozambique. Indeed the intuition and anecdotal evidence outlined above motivates the idea that cell phones will lower price dispersion and enhance market efficiency. Performing an analysis of a specific market in turn allows us to exploit the rich nature of comprehensive microeconomic data sets and produce estimates that are more accurate and informative than similarly-aimed cross-country analyses.

Section II—Background Information and Data

In practical terms, the expansion of mobile networks in the developing world has meant the introduction of a new and disruptive form of communication technology to end users. When we attempt to quantify the potential benefits of mobile usage, the underlying phenomenon we are in fact measuring is the impact of increased access to information—be it through closer connections with family or colleagues, knowledge of the price and availability of certain goods, or otherwise—on consumer behavior and market efficiency.

Given the informational component of mobile phones discussed above, a natural basis for an empirical strategy comes from the vast literature on consumer search theory. In his seminal research on the importance of information, Stigler suggests that "Price dispersion is a manifestation- and, indeed, it is the measure of—ignorance in the market," (Stigler 1961 p.214), whereby he acknowledges that price dispersions (i.e. a deviation from the LOP) emerge due to the existence of search costs to buyers and sellers for goods. He further posits that "…the optimum amount of search will be such that the marginal cost of search equals the expected increase in receipts" (Stigler 1961 p.216). The introduction of a new search technology that significantly reduces the marginal costs of search therefore holds theoretical promise.

As we consider the case of developing agricultural markets, the importance of search costs becomes even more acute. If, for example, price information travels by person (in the absence of radio, telephone, or other form of ICT), then the cost of search may be prohibitively high. In the extreme case, consider a farmer who needs to walk to a marketplace or resale location in order to obtain information on prices—in such a scenario, the farmer is unlikely to engage in much search, and will likely be forced to blindly choose both a day and a marketplace in which to sell his or her goods. The result of such high search costs will in turn yield marketplacees that are geographically segmented, and create persistent violations to the "law of one price."

Contemporary search-theoretic models apply a similar logic to developing agricultural economies. Using Nigerien grain traders as an example, Aker (2008) proposes that decreases in search cost will a) increase the overall number of marketplaces a trader will search, b) increase the reservation price among traders, and c) will reduce the variation in prices across marketplacees. While the theoretical model provides a more rigorous framework, the intuition she presents is straightforward—as the marginal cost of search decreases to farmers and traders, they are in turn better able to seek out the best prices for their goods across both space and time. This phenomenon has immense welfare implications, as the overall level of price dispersion should decrease as well as bring stability to prices across all marketplaces.

The current study employs the search-theoretic models outlined by Aker (2008) in an attempt to quantify the impact of mobile phones in a developing-economy setting. The subsequent analysis operationalizes the theoretical model by observing and analyzing the impact of mobile networks in Mozambique's market for Common Beans, a staple crop. Specifically, the strategy employed hypothesizes that the emergence of mobile phones will coordinately increase the informational flows among farmers and traders, a phenomenon which will become empirically visible through a reduction in the dispersion of prices among the country's dispersed agricultural marketplaces.

Mozambique Background

Any successful empirical investigation must be based on a model that is intuitive and relevant to the subject in question. The necessary first step of the current study is therefore to identify the character of Mozambique's agricultural markets, build an understanding of how these markets function and how the individuals within behave, and then consider how an intervention such as mobile telephony might perform within that space. The current realities we observe in Mozambique are then placed within the context of classical market theory to identify any discrepancies that exist between the two. From this point it is then possible to identify the channels through which mobile phones might remedy persistent market failures and construct more meaningful empirical models.

Overview

Located in sub-Saharan Africa along the Indian ocean, Mozambique remains quantitatively one of the poorest nations in the world, with a per capita income of just $372.04 and a ranking of 184 on the Human Development Index (out of 187) (World Bank 2011). Historical circumstances and political uncertainty have coordinately played a detrimental role in fostering economic and social development, however political stability in recent decades has generated positive trends throughout the country.

The current landscape of Mozambique is in large part defined by its former status as a colonial state of Portugal. As early as the turn of the 16th century, Portuguese traders had established a presence in areas along the northern coast and up the Zambezi River, and subsequently continued to establish dominance throughout the following centuries. By the early 1900s, the Portuguese had created a firmly established colonial power and exercised absolute authority throughout the territory.

As was typically the case throughout European colonies in Africa, the Portuguese implemented extractive and detrimental institutions aimed at promoting European interests—labor laws reserved skilled jobs for Portuguese colonists, while access to education was mostly denied to native Mozambicans. Furthermore, the Portuguese placed little emphasis on investing

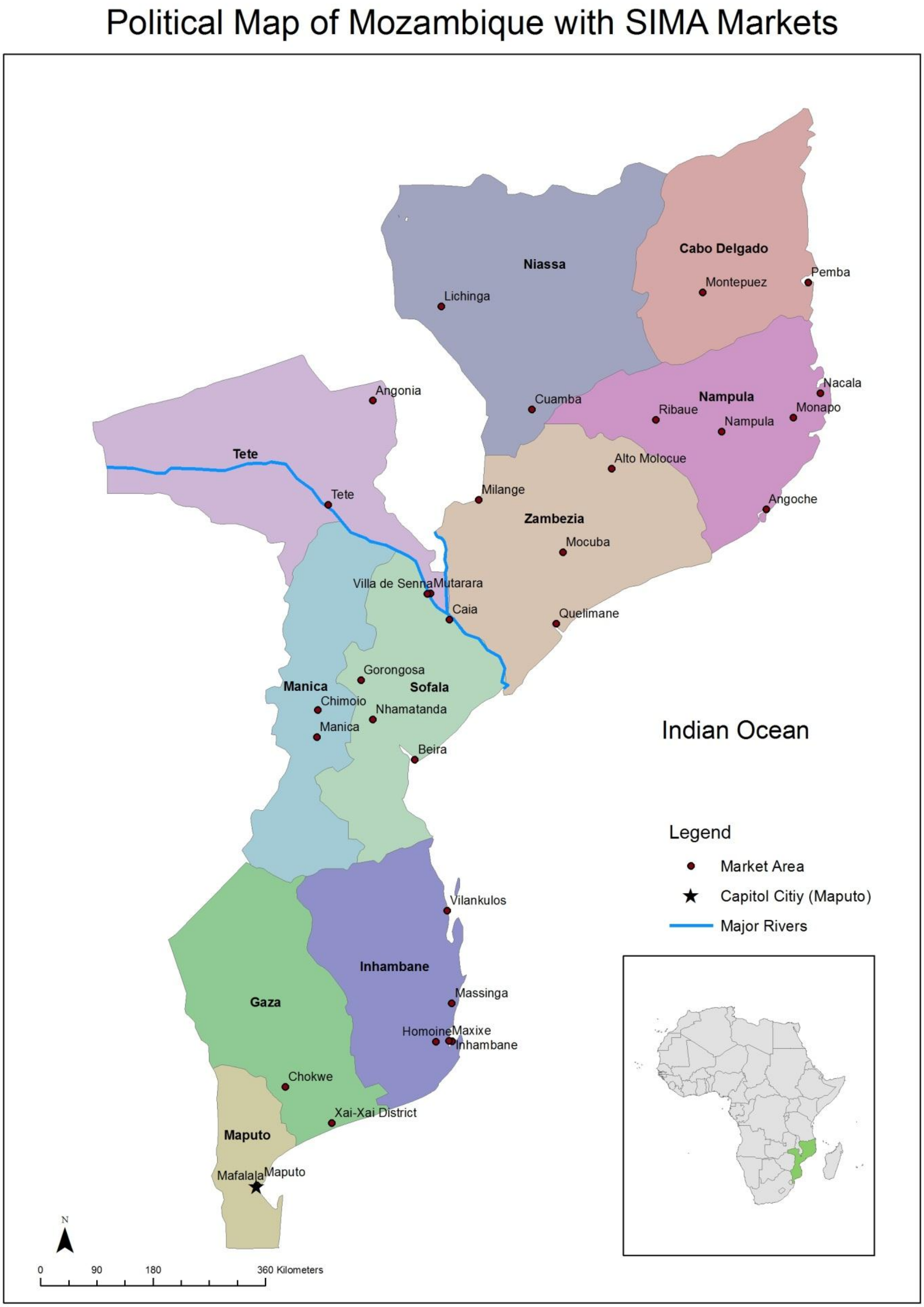

Political Map of Mozambique with SIMA Markets
Cabo Delgado
Pemba
Montepuez
Niassa
Lichinga
Nacala
Nampula
Monapo
Ribaue
Nampula
Cuamba
Angonia
Tete
Alto Molocue
Tete
Milange
Angoche
Zambezia
Mocuba
Villa de Senna
Mutarara
Caia
Quelimane
Gorongosa
Manica
Sofala
Chimoio
Nhamatanda
Manica
Indian Ocean
Beira
Legend
Market Area
Capitol Citiy (Maputo)
Major Rivers
Vilankulos
Inhambane
Massinga
Gaza
Homoine
Maxixe
Inhambane
Chokwe
Xai-Xai District
Maputo
Mafalala
Maputo
N
0
90
180
360 Kilometers

Figure 4.

in social or physical infrastructure that would aid the domestic economy, and instead built transportation lines that promoted economically lucrative industries such as mining and trade with Mozambique's inland neighbors.

Widespread support for independence grew by the early 1960s under the socialist-backed FRELIMO (*Liberation Front of Mozambique*) Party, with independence finally being achieved in June of 1975 in the wake of domestic upheaval in Portugal. Following independence, some 90% of the Portuguese settlers left Mozambique, resulting in a massive deficit of skilled administrators to oversee economic and political function. The remaining political system under FRELIMO maintained a socialist bent, and sought to centralize economic planning by placing heavy regulation upon agricultural markets.

While these economic policies became increasingly problematic, regional political tensions began to mount as well—the FRELIMO party had become an outspoken opponent of the Rhodesian and South African apartheid governments, and by the early 1980s Mozambique had come under violent aggression from RENAMO (*Mozambique National Resistance*), an apartheid-backed anti-socialist group created to destabilize unfriendly governments in the region. The violent outbreaks eventually escalated into an all-out conflict, and atrocities against civilian populations resulted in the deaths of as many as 1 million people (Tarp et al. 2002). Meanwhile, what little infrastructure had been left by the Portuguese was largely destroyed, and the costs of failed economic policies coupled with increased defense spending pushed external debt to unsustainable levels.

1986 saw the collapse of the Mozambique economy as civil war, misguided economic policies, and macroeconomic instability converged to topple the already weakened authority of the central government. In 1987, the FRELIMO-controlled government introduced the Economic Rehabilitation Plan (Tarp et al. 2002, p.27) with the support of the IMF and the World Bank which employed "standard" structural adjustments. Prices were largely liberalized, however minimum producer prices for certain items, including common beans, remained in effect until as recently as 1996 (World Bank 2006; Tarp et al. 2002).

The ending of violence in 1992, along with stabilization efforts, reversed the economic decline experienced throughout the 1980s. Over the past decade, Mozambique has largely stabilized, with income steadily increasing as inflation was brought to sustainable levels and the macroeconomic environment strengthened.

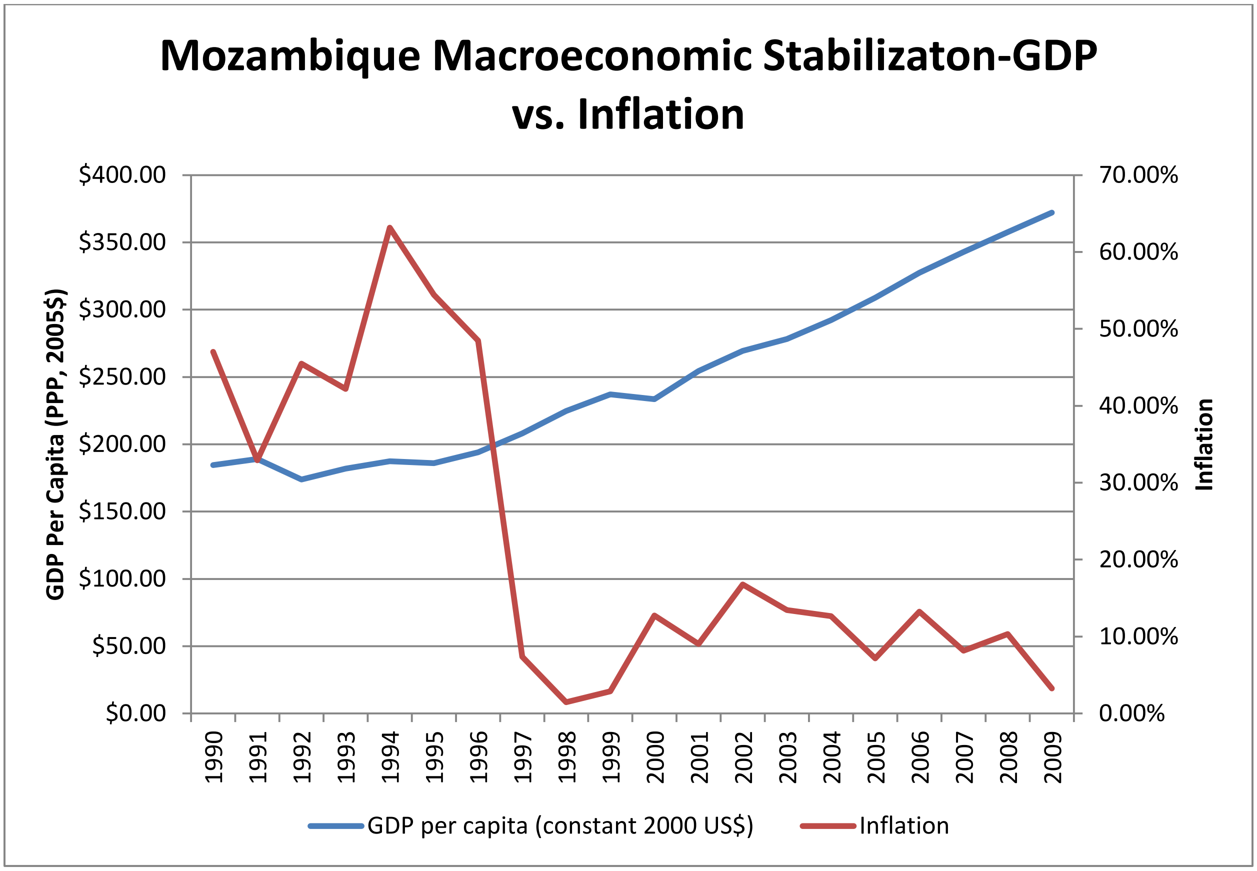


Figure 5. Source World Bank WDI 2011.

Infrastructure

The effects of historical circumstances, although diminishing, remain persistent throughout Mozambique even today. Chronic underinvestment in the capital stock, for instance, has resulted in severely inadequate infrastructure—currently only 20-25% of roadways are paved, and what railways do exist travel primarily from east to west and connect the major port cities of Beira, Sofala, and Maputo with neighboring countries to the west.

Table 1 Road Quality by Region (kilometers)

	Road Quality			
Region	**Primary**	**Secondary**	**Tertiary**	**Grand Total**
North	2937.8 (21.4%)	10257.3 (74.8%)	512.8 (3.7%)	13708.0
South	2462.8 (28.6%)	5973.9 (69.4%)	168.8 (2.0%	8605.6
Total	5400.6 (24.2%)	16231.2 (72.7%	681.7 (3.1%)	22313.6

Source: World Bank GIS data

Table 2. Road Quality by Region (kilometers)

	North	**South**	**% Difference**
Average Travel Time Between Marketplaces (minutes)	764.1	650.1	17.54%
Average Distance Between Marketplaces (km)	668.6	656.0	1.91%

Source: World Bank GIS data

The inadequacy of infrastructure is overwhelming—in an extreme example we find there exists essentially no transportation linkages that cross the Zambezi River, a condition that effectively isolates the northern and southern provinces from one another.[2]

[2] Prior to 2009, there were only two bridges linking the northern and southern regions—one is in the northwestern town of Tete, while the other—the so-called Dona Ana Bridge—connected the market towns of Villa de Sena and Mutarara. While the Dona Ana bridge offered the most direct and convenient route over the Zambezi, it was destroyed during the civil war and was not rebuilt until 1995 as a single-lane auto bridge. The Dona Ana was closed again for renovation in 2006. A third alternative has existed for some time—a ferry at the city of Caia offered transportation between the north and south, however it was expensive, time consuming, and service was often interrupted due to flood conditions on the Zambezi. In 2009, construction ended on a new bridge that will replace the Caia ferry.

Infrastructure of Mozambique

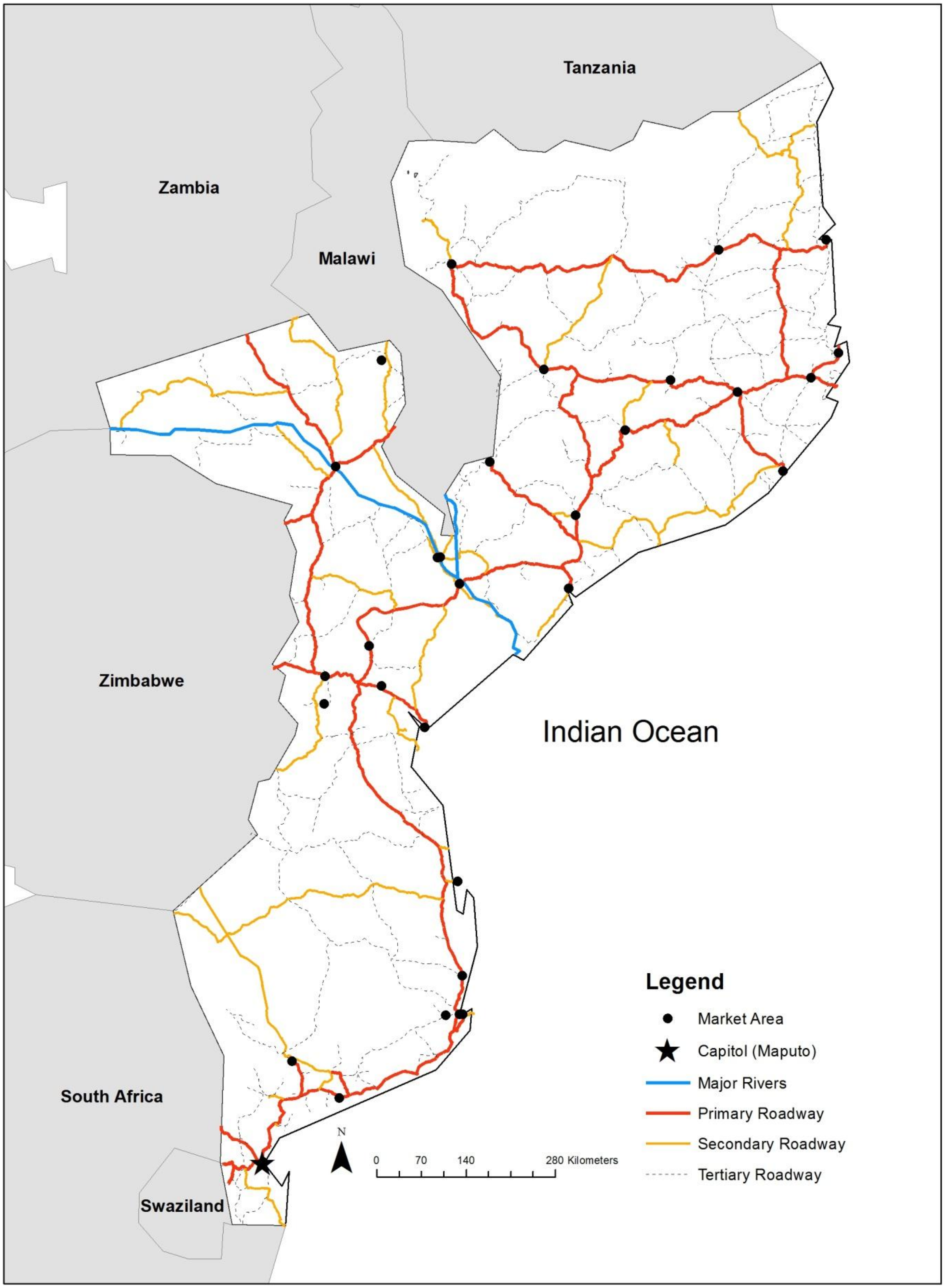


Figure 6.

The Agricultural Economy

Mozambique is primarily rural, with approximately 70% of its population living outside of urban areas (World Bank 2011). Consequently, agriculture has remained a vital component of the Mozambican economy—current estimates show that agricultural output accounts for up to 32% of GDP and likewise employs 80% of the current labor force. In addition, the majority of crop production is carried out by smallholder farmers, making an analysis of the agricultural market system especially relevant to discussions on overall welfare conditions (Donovan and Tostão 2010, World Bank 2011).

Agricultural systems are not homogeneous across Mozambique, but vary according to region. The northern provinces, for instance, have favorable agro-climatic conditions for crop production, while the south has less arable land and is more susceptible to drought. Furthermore, the north is in general more rural, whereas the south is host to some of Mozambique's larger urban centers, including the capital city Maputo.[3] The discontinuous transportation routes between the north and south, however mean that northern provinces often generate a net *surplus* of crops and are hence net exporters of agricultural goods to neighboring Malawi (Tschirley and Santos). In contrast, the south often experiences production shortages and is in turn a net importer of foodstuffs from South Africa.

Table 3. Average Crop Prices between the Northern and Southern Provinces

	Avg. Price (2005 Meticals/kg)		
Crop	North	South	% Difference
Common Beans	0.15	0.18	21%
Lrg. Groundnuts	0.10	0.20	97%
Ordinary Rice	0.13	0.12	-6%
White Maize	0.03	0.04	31%

Source: SIMA 2011

[3] For an interesting analysis of regional staple crop production and trade using GIS spatial analysis, see Tschirley, Haggblade, and Longabaugh (2009)

The findings presented thus far outline the importance of agriculture for both providing a livelihood to a majority of Mozambicans as well as for promoting overall economic growth and stability. Likewise, we find that current market institutions and infrastructures are often insufficient to allow for the optimal flow of goods between marketplaces, and are likewise vastly different between the northern and southern regions. Subsequent empirical analysis will therefore remain mindful of these structural elements of the Mozambican economy as we construct analytical specifications.

Cell Phone Data

Cell phones were introduced in Mozambique in 1997 through a state-owned entity called MCel. At the beginning, access to mobile service was limited by the fact that a mobile account required a contract and "proof of good credit," a policy that precluded a large number of users (Brower & Brito 2012). These restrictions were relaxed in 2001, and by 2003 the mobile market saw the competitive entry of a private operator, Vodacom (Brower & Brito 2012, Ngugi et al. 2007).

The introduction and subsequent liberalization of the mobile market in Mozambique has in turn catalyzed a trend of rapid adoption that mirrors that of other nations around the globe.

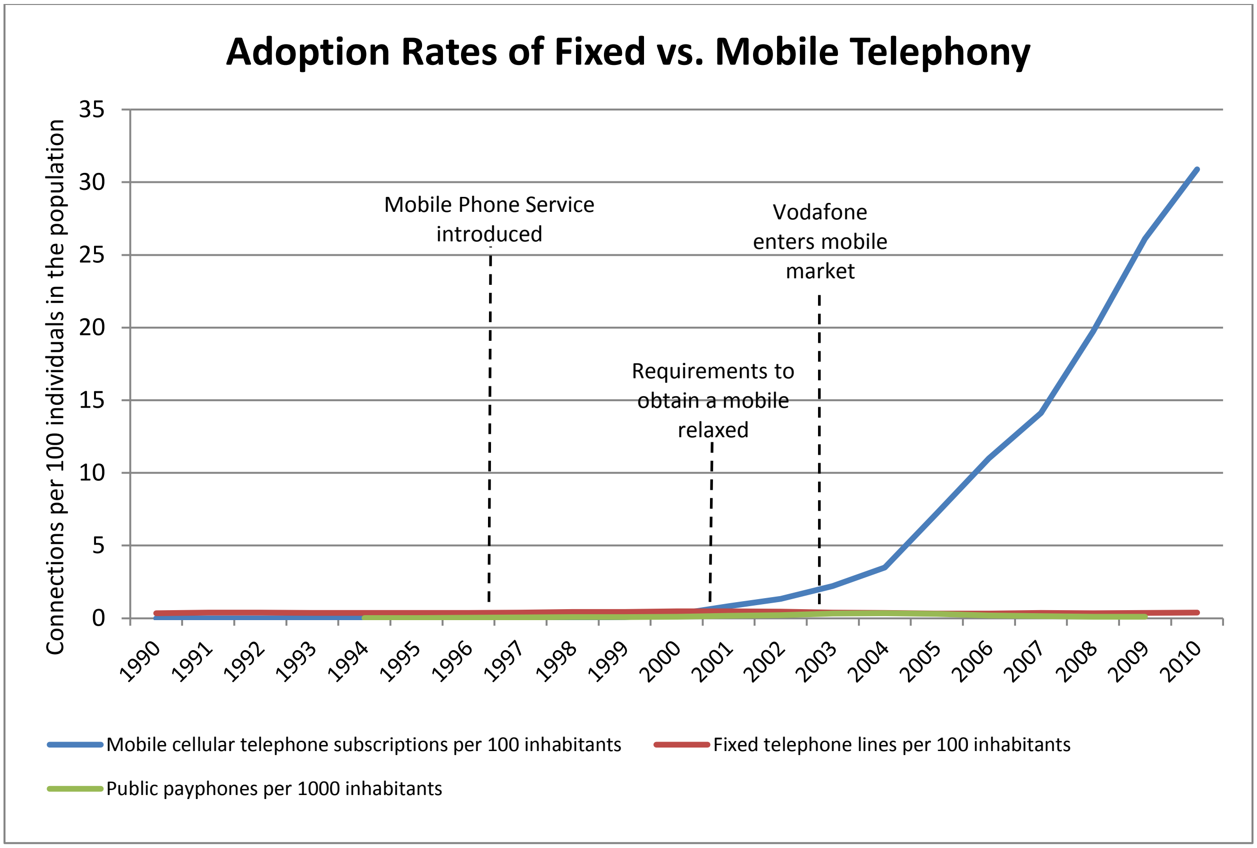


Figure 7. Source ITU (2010).

Coupled with the discussion thus far, the implications for the trends depicted in Figure 7 become clear—in a large country where poor telecommunications and transportation infrastructure make communication difficult, the introduction of a mobile phone may well hold significant promise as a means of bridging the discontinuities between marketplaces, and could in turn promote an overall shift towards efficiency in the agricultural sector.

As networks developed, operators began to extend network coverage throughout Mozambique—while coverage was first implemented in major cities and along major roadways, by 2009 we find that all but two marketplaces (Angónia and Manica) in our sample had received a cell tower.[4]

[4] Note: In this context, we define a market as being "treated" if there is a cell tower proximate to the market area itself.

Table 4. Year of Mobile Service Introduction

Marketplace	**Year**	**Province**	**North or South**
Alto Mol	*2004*	Zambezia	*North*
Angoche	*2003*	Nampula	*North*
Angónia	*not covered*	Tete	*North*
Beira	*2000*	Sofala	*South*
Caia	*2004*	Sofala	*South*
Chimoio	*2000*	Manica	*South*
Chókwè	*1999*	Gaza	*South*
Cuamba	*2003*	Niassa	*North*
Gorongoz	*2003*	Sofala	*South*
Homoíne	*2004*	Inhambane	*South*
Inhamban	*2001*	Inhambane	*South*
Lichinga	*2002*	Niassa	*North*
Mafalala	*1997*	Maputo	*South*
Manica	*not covered*	Manica	*South*
Maputo	*1997*	Maputo	*South*
Massinga	*2003*	Inhambane	*South*
Maxixe	*2001*	Inhambane	*South*
Milange	*2004*	Zambezia	*North*
Mocuba	*2003*	Zambezia	*North*
Monapo	*2005*	Nampula	*North*
Montepue	*2003*	Cabo Delgado	*North*
Mutarara	*2006*	Tete	*North*
Nacala	*2001*	Nampula	*North*
Nampula	*2001*	Nampula	*North*
Nhamatan	*2003*	Sofala	*South*
Pemba	*2002*	Cabo Delgado	*North*
Queliman	*2001*	Zambezia	*North*
Ribáuè	*2005*	Nampula	*North*
Tete	*2001*	Tete	*South*
Vilancul	*2002*	Inhambane	*South*
Sena	*2006*	Sofala	*South*
Xai Xai	*2002*	Gaza	*South*

Survey data, both through official government reports as well as additional academic work, estimates that the number of active mobile phones in Mozambique is between 2.7-3.1 million users (Brouwer and Brito 2012). Although generating an exact figure is difficult due to the nature of pre-paid service, the undisputed fact remains that mobile phones are becoming increasingly available throughout Mozambique. As these trends of adoption continue and the “network” effect of mobiles continues to grow, we expect that information gaps will largely disappear and we should in turn see a discernible effect of mobiles in our sample price data.

Data

This study employs three primary datasets. The first includes price data from the *Sistema De Informação De Mercados Agrícolas De Moçambique*, or *SIMA*, which reports the prices of 27 items from 32 distinct market areas across Mozambique. For the sake of analysis, we focus on one particular crop within the *SIMA* archives, Common Beans. The reasoning for this selection is twofold—first, common beans (also known as sweet beans or *feijão manteiga)* are an essential commodity for the Mozambique agricultural economy—estimates taken from government survey data indicate that the production of common beans increased by over 90% between the ‘95/‘96 and ‘02/’03 harvest seasons (owing largely to increases in consumer demand) while other sources find that common beans are a significant source of calories across all income groups (Boughton et al. 2006). Second, the *SIMA* dataset contains a large number of missing values for certain series, and, consistent with their economic importance, common beans contain some of the most thorough series within our dataset.

SIMA reports data beginning in 1991, however there are a large number of missing values in many of the series during the initial years of the program. Furthermore, the political and regulatory climate in the early 1990s adds further reason to be skeptical of these early data. For these reasons, we choose to drop observations prior to 1997. Table 3 provides summary statistics for Common Beans. [5]

Table 5-Summary Statistics for Common Beans

Region/Province	# Obs	Avg. price (2005 meticals/kg.)	s.d.
North	**36491**	**0.149**	**0.110**
Cabo Delgado	5387	0.182	0.117
Nampula	15637	0.141	0.117
Niassa	3257	0.146	0.101
Tete	3212	0.139	0.089
Zambezia	8998	0.149	0.100
South	**40113**	**0.181**	**0.113**
Gaza	5457	0.205	0.122
Inhambane	10914	0.158	0.131
Manica	7673	0.195	0.100
Maputo	6204	0.210	0.083
Sofala	6504	0.159	0.108
Tete	3361	0.172	0.090
Grand Total	**76660**	**0.166**	**0.112**

Source: SIMA 2011

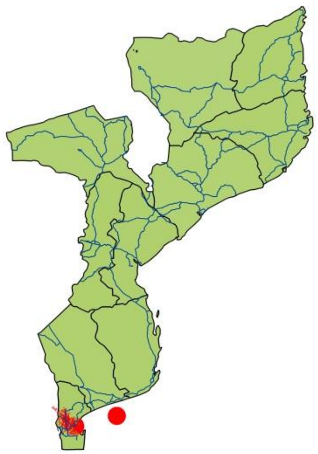
The second dataset consists of cell phone tower locations along with the year each tower was constructed. We then use ArcGIS mapping software to generate a series of coverage variables (described below) for use in our analysis. Due to the potential for selection bias in the placement of cell towers, a primary concern for our empirical work centers on the pattern with which these towers were introduced. Analysis of the rollout of mobile towers over time (see figure below) suggests that cell phone service was introduced gradually, and with preference given to urban areas.

As urban coverage became complete, it appears that a second wave of network expansion occurred along the major roadways between the various market towns and cities. Visual inspection of these data suggests that the rollout of mobile networks is unlikely to be random, and

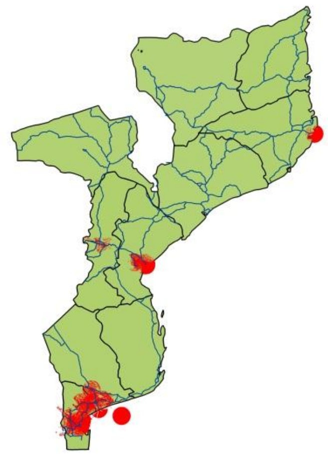
[5] The *Metical* is the official currency used in Mozambique. In 2005/2006 the Bank of Mozambique redenominated the Metical at a rate of 1000:1, which accounts for the large difference in prices reported between various graphs and charts throughout the text.

<u>Coverage Maps over Time 1997-2009</u>

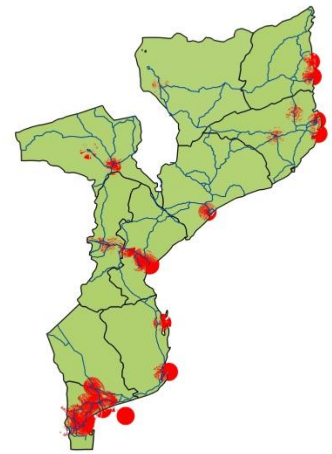
1997



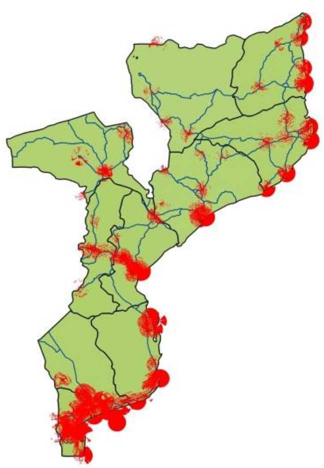
2000



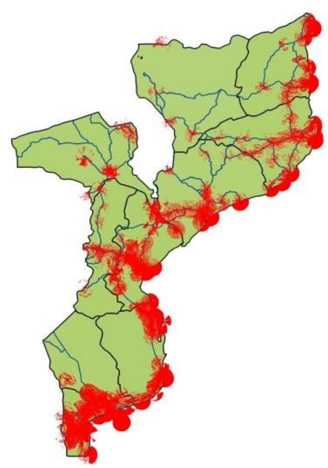
2002



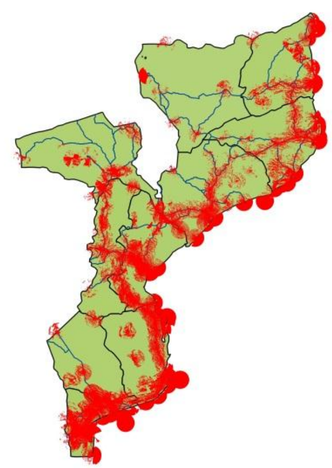
2004



2006



2009



hence there is a risk of simultaneity bias between the introduction of a cell tower and the temporal shift in price dispersion. However, due to the fact that we cannot be certain as to the reasoning behind the placement of towers, and are likewise left without a candidate instrument to employ, we are left to assume that the placement of towers is either exogenous, or, more likely, that the endogenous nature of the treatment effect is unlikely to cause significant bias in our estimates.

The final dataset consists of high-resolution GIS files that include road networks, road quality, and various other forms of infrastructure. We then employ ArcGIS to construct spatial variables such as road distance and travel time, as well as several measures of proximity.

Section III—Empirical Strategy

The current literature on the microeconomic impacts of mobile phones offers several similar but distinct strategies for analysis. Early work by Eggleston et al. (2002), finds that markets in rural China gain efficiency and experience increases in producer and consumer welfare after the introduction of basic telecommunications. Jensen (2007) contributes by observing that the expansion of mobile networks to rural Indian fishing markets dramatically lowers the dispersion and variation of prices among marketplaces, and coordinately reduces wasted catches.

The most relevant example in the literature—and indeed the empirical basis for the current study—comes from work by Aker (2008, 2010) on rural Nigerien grain markets. Using agricultural price data coupled with information on the rollout of mobile networks, Aker finds that the introduction of cellular telephones has a significant impact across the marketplaces in her sample, with an estimated 10-16% reduction in the overall dispersion of prices.

The framework outlined by Aker provides an appealing avenue for the current study. The similarity between the markets under investigation, for instance, makes a transfer of methods appropriate, while the spatial and temporal trends that exist in her sample mirror those found in the Mozambique economy.

Basic Specification

Following the framework developed by Aker (2008, 2010), our empirical strategy specifies a basic model of the following form:

$$Y_{ij,t} = \beta_0 + \beta_1 bothcov_{ij,t} + \sum_{i=1}^{32} \beta_i \gamma_i \sum_{j=1}^{32} \beta_j \gamma_j + \sum_{k=1}^{79} \beta_k \theta_t + \beta_4 drought_t + \varepsilon_{ij,t} \qquad (1)$$ [6]

where *bothcov* is a dummy variable equal to one in years where both marketplaces have cell phone coverage, γ_i and γ_j are market-specific fixed-effects (where $i \neq j$ and $i<j$), θ_t is a time period fixed-effect (quarterly), and *drought* is a dummy variable equal to one in years when there is a drought in Mozambique.[7]

In the basic form specified above, equation (1) estimates the "average" impact of mobile phone rollout by pooling treatment effects across all market pairs. We will then expand upon the basic specification to consider how the impact of cell phones differs along factors such as distance, travel time, transfer costs, "network effects," and other heterogeneous factors shown to

[6] Equation (1) can be estimated either in levels or by taking first-differences. The latter method is appealing because it controls for issues posed by non-stationarity in our series, however employing first-differences coordinately removes a large portion of the variation in our explanatory variables and diminishes the power of our tests. We find no evidence (see Appendix C) of unit roots in any of our series, and consequently opt to estimate equation (1) in levels. We control for heterogeneity and serial correlation employing robust standard errors, and cluster by market pair.

[7] Drought data was obtained from the Centre for Research on the Epidemiology of Disasters' International Disaster Database.

affect price dispersion. While we would like to incorporate transfer costs into our specification, due to a paucity of available data we were only able to obtain transfer costs estimates for a small subsample of years and subsequently omit this variable from our model. Using this smaller subsample, however, we find that our estimated coefficients for *bothcov* actually increases when we include estimated transfer costs, suggesting that this omission will cause us to, if anything, underestimate the effect of mobile phones (See Appendix D for details).

In all cases, the key hypothesis is that information voids and high search costs prevent markets from achieving efficient outcomes, and consequently the introduction of mobile service to a market pair (as expressed by *bothcov*) will systematically reduce the dispersion of prices across all marketplaces. Our parameter of interest is therefore β_1.

The remainder of this section is outlined as follows. First, we consider the differential impact of mobiles across Mozambique's northern and southern regions, and accordingly define a sub-sample of our data. Second, we estimate the average treatment effect across all market pairs in our sample. Finally, we consider the potential heterogeneous effects of mobile phone rollout across both spatial and temporal dimensions. We conclude with an analysis of our results and discuss the plausible implications of our findings.

Regional Effects

We begin our empirical investigation by considering the potential heterogeneous effects of mobile phones across different regions within Mozambique. You will recall from Section II that the country is effectively divided between the north and the south, whereby infrastructure constraints severely limit interregional trade. Given the distinct structural circumstances of each zone, we have reason to suspect, *a priori*, that the treatment effect of mobile phones will accordingly vary. Column 1 of Table 6 displays the estimated average treatment effect across all market pairs in our sample,[8] while Columns 2 & 3 consider only those market pairs in the northern and southern regions respectively.

Table 6. Estimated Impact of Cell Phone Rollout on Price Dispersion (Common Beans)--Regional Effects

	(1)	(2)	(3)
Dependent Variable ($Price_{it}$-$Price_{kt}$)	All Marketplaces	Northern Mkts Only	Southern Mkts Only
Cell Phone Dummy (both covered)	-0.39	0.16	-1.49***
	0.49	*0.74*	*0.55*
Constant	6.15***	5.44***	16.54***
	0.68	*0.68*	*1.92*
Drought Year Dummy	-1.53491*	-0.07024	0.38928
	0.87005	*0.56913*	*1.31776*
Quarterly Fixed Effects	*Yes*	*Yes*	*Yes*
Market-Specific Fixed Effects	*Yes*	*Yes*	*Yes*
Sub-Sample	*All Markets*	*Northern Mkts*	*Southern Mkts*
Observations	15550	9083	6467
Adjusted R-squared	0.18	0.2	0.2

Robust standard errors in italics
* significant at 10%; ** significant at 5%; *** significant at 1%

When we look across all market locations in our sample, we observe no significant effect of mobile phones on price dispersion. When we consider the two regions separately, however, the story changes dramatically—while there remains no significant effect in the north, we observe a negative and significant effect on price dispersion among southern marketplaces. An explanation for this differentiation in cell phones effects lies in the structural differences between these two regions—the north, for instance, is generally more rural than the south, and road net-

[8] Note that, due to infrastructure considerations, we omit all pairs that are divided from north to south—that is, we omit market pairs where one market is in the southern region while the other is in the north, and vice versa.

works and transportation lines are coordinately less developed. In contrast, the southern region is host to the majority of the country's large urban centers, and likewise has more developed mobile networks than the northern regions (Brower & Brito 2012). These circumstances, along with heterogeneous patterns of urbanization and climate, suggest that factors other than information failures are inhibiting trade among marketplaces in the north. Following the results from Table 6, we opt to report in the main body of this thesis an analysis of the southern marketplaces only (we do, however, re-estimate the models in Tables 7-10 using only northern marketplaces for comparison. See Appendix E for the corresponding output).

Average Treatment Effects

With our sample defined, we continue our analysis by considering the average treatment effect of cell phones in greater detail. Table 7 reports several iterations of the basic specification of equation (1), and outlines the various econometric strategies used to evaluate the average treatment effects.

Table 7. Estimated Impact of Cell Phone Rollout on Price Dispersion (Common Beans)--Average Treatment Effects

	(1)	(2)	(3)	(4)
Dependent Variable ($Price_{it}$-$Price_{kt}$)	No Time trend w/ Quarterly Dummies	OLS w/ Market-Specific Fixed-Effects	Fixed-Effects w/ Market-Pair Fixed-Effects	Variable for one market covered
Cell Phone Dummy (both covered) (aka *bothcov*)	-1.49***	-1.49***	-1.38**	-1.68**
	0.55	*0.55*	*0.59*	*0.71*
Cell Phone Dummy (one covered) (aka *onecov*)				-0.17414
				0.53018
Constant	16.51843***	16.54***	7.51***	16.67***
	1.94086	*1.92*	*0.74*	*1.9*
Drought Year Dummy		0.38928	2.29278***	0.33
		1.31776	*0.60646*	*1.3*
Quarterly Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*
Market-Specific Fixed Effects	*Yes*	*Yes*	*No*	*Yes*
Sub-Sample	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*
Observations	6467	6467	6467	6467
Adjusted R-squared	0.2	0.2		0.2
Number of Groups	--	--	110	--

Robust standard errors in italics

* significant at 10%; ** significant at 5%; *** significant at 1%

Due to the potential seasonal effects of agricultural prices, we begin in Column 1 by reporting the average treatment effect for all southern market pairs using quarterly fixed-effects, and find that the magnitude of the coefficient on *bothcov* is both negative and significant. The estimated coefficient on *bothcov* in Column 1 therefore suggests that, on average, the estimated impact of being mutually connected to another market pair will lower price dispersion by an estimated 1.49 meticals per kilo. Column 2 adds a drought year variable to the model, and while we find the coefficient on *drought* is indeed significant, there is no appreciable difference in our coefficient of interest.

Unobservables and Omitted Variable Bias

A central concern in the current study is the existence of unobservable inter- and intra-market traits and omitted variable bias. We attempt to account for these potential biases by employing a fixed-effect framework, and include controls along both temporal and spatial dimensions.

Implementing a fixed-effects methodology across the spatial dimension, however, offers two potential strategies—the first method is to employ a market *pair* specific fixed-effects estimator, while the second strategy would be to include a separate dummy variable *for each individual market* in a particular market pair in our specification. The former method is perhaps the more "effective" strategy, as such an estimator will remove all unobserved effects that exist among each unique pair, however by construction a pair-specific fixed-effects estimator ignores all variation in our explanators across market pairs in our sample.

Alternatively, we can include a dummy variable for *each individual market* in a pair—such a strategy will control for the unobserved heterogeneity unique to each marketplace (but not necessarily between a specific pairing) without sacrificing the information contained in the variation across all pairs in our sample. We rely on the second strategy because the first strategy sacrifices too much information, and consequently find that we are unable to achieve efficient estimates.

For the sake of comparison, Column 3 re-estimates the model in Column 3 using a *market-pair* fixed-effect. Although we still observe a negative and significant effect of mobile phones, our point estimate and significance level for *bothcov* decrease slightly. Furthermore, we find that when we augment the model to include additional covariates, the market-pair fixed-effects framework eliminates too much of the cross-market variation in our explanators to obtain significant results (results not reported).

Column 4 in turn considers the effect of mobile phones in instances where only one marketplace in a market pair receives a cell tower (as indicated by the dummy variable *onecov*). Consistent with our hypothesis, we find that cell phones have no significant effect on the price dispersion between market pairs where only one location has mobile coverage.[9]

Overall, the results in Table 7 find that the introduction of mobile phones throughout Mozambique has had a significant effect on price behavior in the market for common beans. These findings are consistent with our hypothesis, and lend support to the notion that informational failures are indeed a contributing factor to persistent price dispersion in the agricultural sector.

[9] A priori, we expect the coefficient on *onecov* to be insignificant. Our hypothesis maintains that mobiles effectively lower search costs to traders and farmers— it therefore follows that in instances where a marketplace remains isolated (i.e. in instances where *onecov* equals 1) the reductions in search costs cannot be realized, and hence we find no effect. See Appendix F for a more detailed discussion.

Heterogeneous Effects

The results presented thus far depict the average effect of treatment throughout all markets in our sub-sample, and lend support to the notion that mobile phones are enhancing market efficiency in a systemic manner throughout Mozambique's agricultural system.

While these results enforce the overall effect of mobiles, they fail to provide insight into the specific channels through which mobiles are facilitating market function. That is, are mobile phones more effective in instances where markets are further apart, or are connected by roads of poorer quality? Does the efficacy of mobiles change when we consider the size and importance of a market place? These questions are particularly interesting in the context of understanding the welfare outcomes of mobile phone implementation, and likewise provide the empirical detail necessary to inform policy-related issues.

To answer these questions, we augment the basic specification defined thus far and test for possible heterogeneous effects of mobile phones across a multitude of dimensions. The following table outlines our results (for ease of comparison, Column 1 repeats the results of our basic specification in Column 3 of Table 7).

Table 8. Effect of Cell Phone Rollout on Price Dispersion-Heterogeneous Effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent Variable (P_{it}-P_{ij})	Basic Specification	Time Dummies	Distance Dummies	Market Sizes	Network Effects-Teledensity	Network Effects-Total # of Mrkts Covered	Coverage Density
Cell Phone Dummy (both covered)	-1.49***	-0.99*	-1.02		-0.29	1.75	
	0.55	*0.58*	*0.73*		*0.67*	*3.73*	
Coverage Density (25km radius)							-2.08*
							1.17
Cell Phone Dummy (both covered) * Shrt time. Dummy (<3 hrs)		-0.78032					
		0.60079					
Cell Phone Dummy (both covered) * Med time. Dummy (3-6 hrs)		-2.52***					
		0.67					
Cell Phone Dummy (both covered) * Long time. Dummy (6-12 hrs)		-0.31					
		0.47					
Cell Phone Dummy (both covered)*ln(tot. mrkts covered)						-1.25393	
						1.54783	
Cell Phone Dummy (both covered)*ln(teledensity)					-0.71967*		
					0.40949		
Cell*Mkt Size Dummy (both major)				-0.79			
				0.87			
Cell*Mkt Size Dummy (one major)				-1.59290***			
				0.55383			
Cell*Mkt Size Dummy (both minor)				-1.91***			
				0.7			
Cell Phone Dummy (both covered) * Short Distance Dummy (<150km)			-2.18**				
			1.09				
Cell Phone Dummy (both covered) * Med. Distance Dummy (150-500km)			-0.24				
			0.78				
Cell Phone Dummy (both covered) * Long Distance Dummy (500-1000km)			-0.60569				
			0.58662				
Constant	16.54***	16.31***	16.63***	16.75***	16.32***	16.64***	16.19***
	1.92	*1.92*	*1.9*	*1.88*	*1.9*	*1.93*	*1.93*
Drought Year Dummy	0.38928	0.5	0.32	0.32	0.36	0.18	0.95753
	1.31776	*1.3*	*1.32*	*1.32*	*1.35*	*1.42*	*1.17366*
Quarterly Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Market-Specific Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Sub-Sample	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*
Observations	6467	6467	6467	6467	6467	6467	6467
Adjusted R-squared	0.2	0.21	0.2	0.2	0.2	0.2	0.2

Robust standard errors in italics

* significant at 10%; ** significant at 5%; *** significant at 1%

Distance & Travel Time

Column 2 considers the heterogeneous effect on mobile phones and travel time between market pairs.[10] Given the additional costs associated with increased travel time, we expect that the interaction between our cell phone dummy and travel time variable will be negative and significant—if mobiles allow traders to effectively search for prices in distant markets, then the introduction of a mobile connection will result in a higher volume of trade than would otherwise have taken place as traders become more likely to observe and exploit arbitrage opportunities as they arise. Put another way, in the absence of accurate or reliable price information, any potential arbitrage decision is made with some degree of uncertainty on the part of the trader. As the transfer costs increase between two markets, the potential costs of this uncertainty will coordinately grow as well. With the introduction of a mobile phone, a trader can know, prior to committing to travel from one market to another, whether such a trade will be profitable. The hypothesized result is that cell phones will remove these uncertainties, and promote profitable trades that would have otherwise been missed.

Column 2 reports the interaction effect of mobile coverage and with several travel time dummy variables. Interestingly, we find no significant effect for markets that are either relatively close or relatively far from one another (<3 hours and >6 hours respectively), however we do find a significant effect of mobile phones among markets that are between 3-6 hours apart. In the context of the hypothesis above, these results suggest that mobiles are indeed expanding the regional footprint of traders—in the case of nearby market pairs, it is likely that preexisting networks allow for positive information exchange through some other means (potentially by person

[10] Travel times are represented here as approximate travel times by car or truck. The data for this variable come from high-resolution World Bank GIS datasets that formulate travel times based on road distance, quality, and other structural impediments.

or prior experience), while markets that exceed 6 hours in travel time are simply too far for profitable arbitrage to exist regardless of whether information is available or not (in such a case, we would expect that the transfer costs exceed the price differential in all but extreme circumstances).

The significant effect we see for markets separated by this "middle distance" in turn suggests that the introduction of mobile phones is allowing traders to increase the scope of their trade networks. Whereas before information gaps made trade with these more distant markets potentially risky, the advent of mobiles appears to facilitate the exchange of information necessary to incentivize traders to act upon arbitrage opportunities that were previously unknown.

Column 3 reports a similar specification, employing market-pair distance dummies rather than travel time dummies. Given that both Columns 2 & 3 are effectively measuring some element of transport costs associated with road travel, we expect that these results will be similar. Furthermore, because our "travel time" variable takes into account road distance as well as road *quality* data, we rely on it as a more accurate measurement. Regardless, we still find that mobile phones and road distance have a negative and significant interactive effect on price dispersion.

Market Size

In Column 4 we consider the influence of marketplace size and importance using dummy variables to determine whether both marketplaces are "major" markets, whether only one is "major," or whether both are "minor."[11] *A priori*, we expect that the effect of cell phones will be more pronounced in pairs that contain a minor marketplace, whereas the effect will be smaller in cases where both marketplaces are larger. The underlying assumption is that preexisting infor-

[11] We use market size/importance classifications taken from USAID/FEWS

mation flows are likely to exist between established marketplaces (perhaps due to fixed-line telephony, or radio), while smaller markets are coordinately less integrated into regional trade patterns.

In line with our hypothesis, we find that the effect of mobile phones varies according to marketplace size, whereby mobiles have a large and significant effect in cases where only one marketplace is "major" or when both are "minor." These results in turn suggests that mobile phones are being used to connect outlying markets into primary trade patterns, and hence account for the large overall average treatment effect reported in the previous section.

Network Effects

As the number of mobile users increases, the potential benefits of belonging to the network increase to each individual user as well. This spillover, or "network" effect, is clearly seen in the absorption patterns across countries. Recall from Figures 2 & 3 in the introduction that adoption of mobile telephones increases to a break-point—typically around 15-20%--before teledensity levels begin to grow in an exponential fashion. These phenomena are likely to appear in our data as the increased usage of mobiles will in turn increase the number of connected individuals and hence the overall amount of information available. The specification in Column 5 addresses the network effect phenomenon by including an interaction term between our coverage variable and a measure of overall mobile "teledensity" (where teledensity is measured as the natural logarithm of the number of mobile subscribers per 100 people in the population). Interestingly, we find a significant effect of teledensity on price dispersion, however our point estimates for the interaction term remain small, and are only marginally significant at the 10% level. A plausible explanation for the weakness of these results is that traders are in fact among the "early adopters" of mobile phones in these regions—in such a scenario, the effect of cell phones is still realized within the market for common beans, however the continued addition of mobile subscribers by non-market persons is of no consequence.

We test this intuition by replacing *teledensity* with an alternative measure of network size (in this case, the total number of marketplaces covered by cell service), and re-estimate the specification from Column 6. Interestingly, we find that while the interaction between our coverage dummy and the new measure of network size does in fact have a negative and a larger-in-magnitude coefficient than does the coefficient on *Cell Phone Dummy*log Teledensity*, we find that the effect is insignificant.

While the observed relationship is in fact insignificant, it is important to note that the standard errors are large and our failure to obtain significant results may be driven by a lack of variation in the underlying explanators. Indeed visual inspection of the data reveals that this is a distinct possibility:

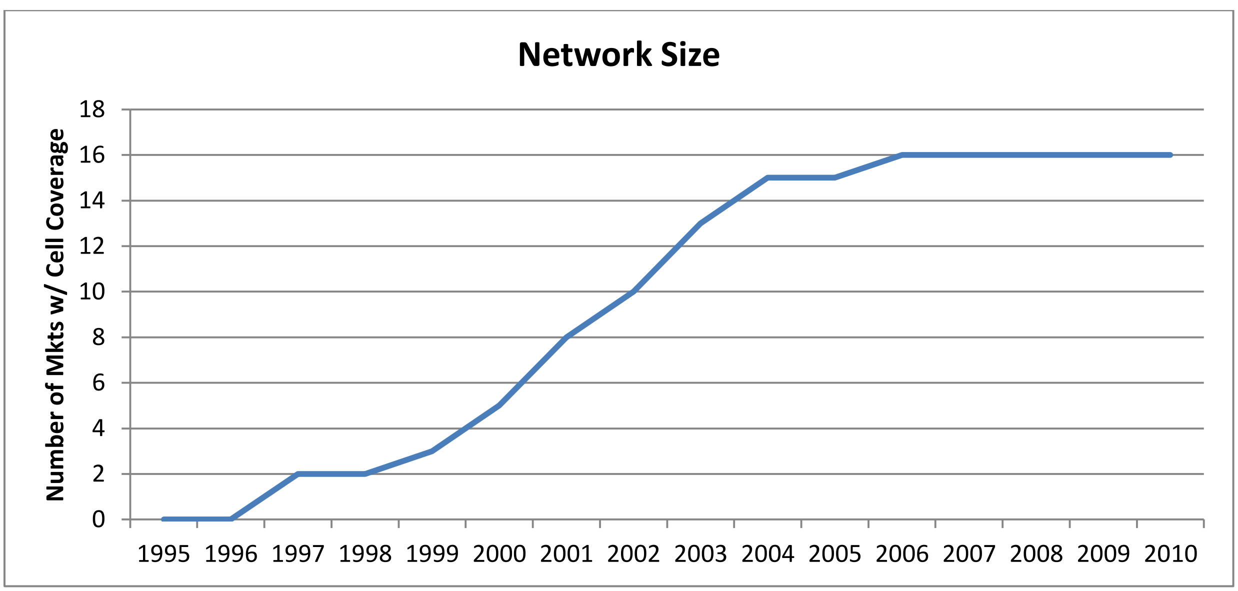


Figure 8. Number of Southern Marketplaces Covered by Mobile Service

As Figure 8 indicates, adoption among marketplaces in the south was strong throughout the early years, but reached a saturation point in 2004. While the early period in our sample shows some amount of variation, the relatively static nature of adoption in the latter portion of our time series along with the relatively few marketplaces in our sample may in fact be masking the underlying network effects and preventing us from obtaining significant results.

The conclusion from Columns 5 and 6 is that while we see downward pressure on price dispersion as a result of these "network effects," we find that there is an insufficient amount of variation in our data to derive significant estimates.

Coverage Density vs. Coverage Dummies

In Column 7 we re-estimate the specification in Column 1 using an alternative indicator of cell phone coverage that measures the percentage of a marketplace's surrounding area (within a 25km radius) that is covered by cell service (see appendix G for a detailed discussion on this variable). The theoretical assumption with these alternative density variables is that they allow us to trace the impact of mobile phones from the farmers in the areas surrounding a marketplace to the traders who operate between market locations and consequently to the overall dispersion of prices among marketplaces. The intuition is that although a simple dummy variable for the presence of a cell tower allows us to determine whether market centers are "connected," we cannot directly comment on whether farmers who live in the areas outside the market center—but that interact with the marketplace itself—have access to mobile coverage.

In the case of coverage dummy variables, we are therefore implicitly limiting ourselves to understanding the impact of mobile phones as they are used by inter-regional traders—by considering the *quality* of cell phone reception in the areas surrounding a marketplace, we are able to at least glimpse at the degree to which cell phones play the additional role of informing the famers themselves of when—and if possible where—to bring their goods to obtain the highest price.

Furthermore, coverage density variables are likely to be a more accurate measure of cell phone coverage than simple dummies—in certain cases, it appears that while there is no cell tower within the marketplace area itself, the area still receives mobile coverage from other near-by towers. In these cases, we may mistakenly consider a market location as untreated when in fact participants within these market areas have access to mobile networks. Using this alternative measure of price dispersion, we find that our point estimates of the impact of mobile phones is larger in magnitude than the coefficient on our coverage dummies, and remains statistically significant at the 10% level. For the sake of comparison, we re-estimate several of the models from Table 8 using coverage density variables instead of coverage dummies. These results can be reviewed in Appendix B.

Temporal Effects

While we have shown that price dispersion decreases as a result of the mere *introduction* of mobile networks, we remain interested in the possibility that these effects may change over time. Indeed as mobile networks become more established and patterns of use evolve among traders and farmers, we expect that the effect of mobile telephony will become more pronounced as this new technology becomes integrated into normal market behavior. Column 2 of Table 9 considers this phenomenon by interacting our cell phone dummy with a quarterly time trend (Column 1 repeats the basic specification for ease of comparison).

Although our coefficient on the cell phone coverage dummy becomes insignificant, we find that there is a negative and significant effect of an interaction with a quarterly time trend, suggesting that mobiles become more effective with time. While these results may in fact be capturing the residual effect of the increased network coverage that is simultaneously occurring, a feasible alternative is that patterns of adoption and implementation are becoming more efficient as users gain experience with this new technology.

Table 9. Effect of Cell Phone Rollout on Price Dispersion- Temporal Effects

	(1)	(2)	(3)	(4)
Dependent Variable ($Price_{it}$-$Price_{kt}$)	Basic Specification	Temporal Effects- Cell Coverage over Time	OLS w/ Lagged Dependent Variable	A-Bond Estimator
Cell Phone Dummy (both covered)	-1.49***	3.86	-0.75***	-0.42
	0.55	*2.43*	*0.27*	*0.71*
Cell Phone Dummy (both covered)*quarter (time trend)		-0.09282**		
		0.04535		
Lagged Dependent Variable (1 period lag)-Common Beans			0.52491***	0.01901
			0.01947	*0.0251458*
Constant	16.54***	16.30***	-0.3	
	1.92	*1.89*	*3.43*	
Drought Year Dummy	0.38928	0.34	-0.49	2.13461
	1.31776	*1.35*	*0.5*	*1.95084*
Quarterly Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*
Market-Specific Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*
Sub-Sample	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*
Observations	6467	6467	5797	12468
Adjusted R-squared	0.2	0.21	0.41	--
Number of Groups	--	--	--	188

Robust standard errors in italics

* significant at 10%; ** significant at 5%; *** significant at 1%

An additional consideration we test for is the possibility of a lagged effect from the dependent variable. Indeed in cases where information flows slowly between distant marketplaces, we expect that previously known prices are likely to be a strong guiding force in the decision making-process of farmers and traders. To account for the effects of prior price dispersion on current outcomes, we augment specification in Column 2 to include a lagged dependent variable and re-estimate using OLS. Using this methodology, we still observe a negative and significant effect of mobile phones on price dispersion, however our point estimates are considerably diminished. To account for the possibility of a dynamic panel, we further refine our specification and employ the Arellano-Bond estimator. Although we still see a negative effect on our coefficient of interest, our standard errors are of such a magnitude that we are unable to obtain significant results. These findings suggest that there is a strong lagged effect in the observed price behavior, and likewise hints at the fact that mobiles maintain their influence. Ultimately, however, we are left to the conclusion that our data lacks the variation necessary to generate definitive significant results.

Conclusion and Remarks

The estimates reported in Tables 6-9 demonstrate the efficiency-enhancing effects of mobile phones and lend strong support to the theoretical discussion outlined in the previous section. Looking at the average treatment effect across all marketplaces in the southern region, for example, we find that the introduction of mobile phones reduces price dispersion by approximately 1.49 meticals/kilo. These results are indeed compelling, and lend further support to the current policy debate that mobile phones can impart beneficial outcomes to developing markets.

Although we find significant *overall* effects of treatment in our sample, it is important to note that our estimates are both smaller in magnitude and significance than we would expect given results found in similar studies. In addition, we find no discernible impact when we look at the northern marketplaces or across other commodities reported within the *SIMA* database.

Table 10. Effect of Cell Phone Rollout on Price Dispersion-Additional Crops

	(1)	(2)	(3)	(4)	(5)
Dependent Variable ($Price_{it}$-$Price_{kt}$)	Common Beans	Lrg. Ground-nuts	White Maize	Rice	Wheat Flour
Cell Phone Dummy	-1.49***	-0.07	0.09	-0.01	-0.06
	0.55	*0.58*	*0.07*	*0.18*	*0.31*
Drought Year Dummy	0.38928	0.11855	-0.474***	-0.52889*	-0.2391
	1.31776	*0.48361*	*0.16865*	*0.2754*	*0.19325*
Constant	16.54***	4.28***	1.29***	1.30***	0.31
	1.92	*1.19*	*0.16*	*0.35*	*0.77*
Quarterly Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Market-Specific Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Sub-Sample	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*
Observations	6467	6072	7569	7606	3685
Adjusted R-squared	0.2	0.18	0.2	0.24	0.33

Robust standard errors in italics
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 10 provides a glimpse into other areas of the agricultural markets and dramatically illustrates the near zero effect of mobiles on price dispersion in similar settings within Mozambique.

Given the success of mobile phones found in similar studies in the literature, we are left to consider plausible alternatives to why we observe such ambiguous and insignificant results. A simple explanation may be that there is insufficient variability in our explanators, the end result of which is that we are simply unable to derive efficient estimates.

An alternative explanation, however, comes from a separate strand of literature that focuses on market efficiency from the perspective of spatial efficiency versus spatial integration. Recent research by Barrett (2001), for example, argues for a distinction between "spatial integration" and "spatial efficiency." By his designation, the former constitutes a flow-based definition where markets are said to be "integrated" with one another if trade exists between various marketing locations. In contrast, markets are said to be "spatial *efficient*" when traders are able to drive price dispersion towards transfer costs, implying that zero marginal benefits exist from additional arbitrage in a Pareto equilibrium (Tostao & Brorsen 2005, Barrett 2001). In cases with unrestricted trade and/or perfect integration between marketplaces, efficiency can be measured using data on prices and transfer costs whereby a market pair achieves some level of price dispersion such that:

$$Price\ Dispersion = \left|Price_{i,t} - Price_{k,t}\right| - transfer\ costs + \varepsilon_t \qquad \text{for } i \neq k \qquad (2)$$

where efficiency is obtained (i.e. the "Law of One Price" is satisfied) when the expected value of equation (2) is 0. The difficulty with strategies that solely employ price data is that transfer costs or any unobserved trade discontinuity (for example due to inadequate transportation infrastructure or policy changes) will cause biased or inconsistent parameter estimates (Tostao & Brorsen 2005 p.206). In these cases, empirical results may (incorrectly) conclude that integrated markets are "statistically uncorrelated and…functionally isolated…[while] markets without trade links can be found to be price correlated and deemed efficient" (Tostao & Brorsen 2005).

Barrett (2001) further posits that evaluating efficiency based purely on adherence to the law of one price equates to assuming “continuous, unrestricted trade flows” (p.23). In the presence of disintegrated markets, however, it follows that multiple equilibria may exist conditional upon the size and scope of these discontinuities. In such cases, prices between isolated marketplaces may be statistically independent, and tests that look only at the equality condition may be invalid (p.23).

Returning to the case of Mozambique, we find that market disintegration not only exists, but is pervasive throughout the country. Several studies, for example by Ciera and Arndt (2008), Tostao and Brorsen (2005) and Penzorn & Arndt (2002) find overwhelming evidence—both anecdotal and empirical—that agricultural marketplaces in Mozambique are plagued by trade discontinuities, and furthermore that transfer costs constitute a significant amount of the observed price dispersion.

Connecting these studies with the empirical work in this paper, we propose that the ambiguous results obtained are not due to the inefficacy of mobile phones *per se*, but rather our estimates are being biased by these persistent trade discontinuities. While we attempt to control for these effects as much as possible, the dampened effects seen in the results above as well as in the appendices point to the fact that barriers to the flow of goods is likely the limiting factor to market efficiency in our sample.

Overall, the results presented thus far suggest that mobile phones do have a discernible impact in the market for common beans. The reduced magnitude of the treatment effect, however, along with the discussion concerning integration, points to the fact that the efficacy of mobile phones for development—at least in the context of agricultural markets—is predicated on sufficient market integration and a reduction of trade discontinuities. Going forward, development strategies need to consider these constraints when implementing policies geared toward agricultural development. From a theoretical standpoint, information remains a key underlying condition necessary for healthy markets. The results from the current study, however, remind us of the fact that information is merely a *complement* to other forms of infrastructure, not a substitute.

Conclusion

The current study attempts to provide quantitative insight into the efficacy of mobile telephony for development by considering the specific case of Mozambique's agricultural commodity markets. Although our study maintains a narrow focus, the results presented here expose phenomena and trends that inform research and policy issues throughout other similar development settings.

Overall, we find that while there is a marginal average effect of mobiles in the market for common beans, these results are not persistent when we look across other commodities and/or regions within Mozambique. Given these results, we are ultimately left to conclude that informational constraints are not of paramount importance with regards to market efficiency and integration in our sample. In the context of the current literature on mobile telephony, we therefore present an important realization whereby cell phones—although shown elsewhere to be both empirically and anecdotally important development tools—are not a panacea but rather are one of several possible interventions that must be looked at from a systemic viewpoint. That said, the evidence presented both here and throughout the literature suggests that once certain conditions are satisfied (i.e. sufficient infrastructure exists to allow for the free-flow of goods across space) mobiles phones will have an appreciable and significant impact on price dispersion across a range of different countries and market types.

The insignificant results presented in the current study therefore do not undermine the potential of mobile telephony, but rather enforce the need to consider policy interventions from a holistic standpoint. As governments and aid agencies consider new avenues for future strategies, it is therefore important to form the realization that efficiency and development can only be achieved through the coordination of multiple market systems. As such, mobile phones are unique in that they provide an inexpensive technology that enhances the overall efficiency among these various market structures, however without these corresponding market components (i.e. transportation infrastructure), there is little room for mobiles to generate any effect whatsoever.

The determination of this study is therefore that while mobile phones may indeed stimulate some marginal effect in a given sample, the true potential of this new technology can only be utilized given that additional constraints do not further limit the ability of markets to function. From a policy standpoint, it is therefore vital that future strategies promote mobile network development in tandem with transportation infrastructure enhancement. In some sense, the result of these two forms of development are greater than the sum of their parts, whereby the simultaneous increase in information coupled with decreased transportation costs will promote inter-marketplace trade, facilitate optimal arbitrage, and generate efficient market outcomes.

Further research on the subject of mobile phones is therefore necessary to build a more solid understanding of the microeconomic impacts of mobile phones for development. The current microeconomics literature, although compelling, is limited in size and scope. As mobile networks continue to expand and patterns of use continue to evolve, further investigation will remain an important means of understanding the manner in which mobiles function, and will help promote the beneficial outcomes this new technology can impart on the development trajectories of the third world.

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Appendix

Appendix A-Additional Summary Statistics

Table A-Summary Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Year	21216	2004.0	3.7	1998.0	2010.0
Month	21216	159.5	45.0	82.0	237.0
Coverage Dummy (both markets covered)	21216	0.4	0.5	0.0	1.0
Coverage Dummy (one market covered)	14460	0.4	0.5	0.0	1.0
Est. % of surrounding market area covered by Mobile Coverage (25km radius)	21216	0.5	0.4	0.0	1.0
Est. % of surrounding market area covered by Mobile Coverage (50km radius)	21216	0.4	0.3	0.0	0.9
Mobile per 100 in the pop. (Country Total)	21216	9.0	10.2	0.0	30.9
Total Number of Markets Covered	14460	12.2	2.8	8.0	15.0
Avg. Travel Time between Mrkts. (hours)	21216	10.8	7.0	0.0	26.6
Avg. Road Distance between Mrkts.	21216	656.0	394.6	0.5	1543.2
Avg. Travel Time between Mrkts. (mins)	21216	650.1	417.6	0.0	1598.0
Transfer Cost Estimates (2001-2005 only)	6936	1.1	0.4	0.4	2.1
Dummy if both markets are "major" markets	21216	0.1	0.3	0.0	1.0
Dummy if one market in a pair is a "major" market	21216	0.5	0.5	0.0	1.0
Dummy if both markets are "minor" markets	21216	0.4	0.5	0.0	1.0
Quarterly Time Trend	21216	53.5	15.0	28.0	79.0
Drought Year Dummy	21216	0.6	0.5	0.0	1.0
Average Price, White Maize	7569	-0.2	1.5	-8.8	8.5
Price Dispersion, White Maize	7569	1.2	1.0	0.0	8.8
Average Price, Wheat Flour	3685	1.3	3.4	-9.5	13.4
Price Dispersion, Wheat Flour	3685	2.7	2.4	0.0	13.4
Average Price, Cow Peas	6219	0.5	6.0	-26.0	26.7
Price Dispersion, Cow Peas	6219	4.3	4.2	0.0	26.7
Average Price, Common Beans	6467	0.0	7.6	-30.2	31.8
Price Dispersion, Common Beans	6467	6.0	4.6	0.0	31.8
Average Price, Rice	7606	0.4	3.2	-12.2	11.4
Price Dispersion, Rice	7606	2.5	2.0	0.0	12.2
Average Price, Sml Groundnuts	6763	0.4	7.1	-55.3	54.7
Price Dispersion, Sml Groundnuts	6763	5.3	4.8	0.0	55.3
Average Price, Lrg Groundnuts	6072	0.6	6.2	-22.0	23.0
Price Dispersion, Lrg Groundnuts	6072	4.9	3.9	0.0	23.0

Note: Summary Statistics are for Southern Markets Pairs only

Appendix B – Coverage Densities

The following table re-estimates the models presented in Table 8, using our “coverage density” variable in place of our coverage dummy variable.

Appendix B. Same as Table 2, only using coverage densities instead of coverage dummy--Market-specific fixed-effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent Variable (Pit-Pih)	Basic Specification	Time Dummies	Distance Dummies	Market Sizes	Network Effects-Teledensity	Network Effects-Total # of Mrkts Covered	Coverage Density
Coverage Density (25km radius)	-2.08*	-1.09	-1.49		-0.95	0.89	-2.08*
	1.17	*1.15*	*1.28*		*1.03*	*4.53*	*1.17*
Coverage Density * Shrt time. Dummy (<3 hrs)		-1.14894					
		0.96168					
Coverage Density * Med time. Dummy (3-6 hrs)		-3.79***					
		1.02					
Coverage Density * Long time. Dummy (6-12 hrs)		-0.56					
		0.93					
Coverage Density*longdist			-1.31524				
			0.94071				
Coverage Density*lognetworktot						-1.18327	
						2.02726	
Coverage Density*logteleden					-0.78282		
					0.53713		
Coverage Density*bothmajor				-1.14			
				1.57			
Coverage Density*onemajor				-2.30038*			
				1.17837			
Coverage Density*bothminor				-2.89*			
				1.51			
Coverage Density*meddist			-0.56				
			1.1				
Coverage Density*shortdist			-3.71**				
			1.79				
Drought Year Dummy	0.95753	1	0.87	0.9	0.68	0.74	0.95753
	1.17366	*1.16*	*1.19*	*1.18*	*1.21*	*1.31*	*1.17366*
Constant	16.19***	15.92***	16.42***	16.42***	16.16***	16.28***	16.19***
	1.93	*1.93*	*1.91*	*1.91*	*1.92*	*1.94*	*1.93*
Quarterly Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Market-Specific Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Sub-Sample	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*
Observations	6467	6467	6467	6467	6467	6467	6467
Adjusted R-squared	0.2	0.21	0.2	0.2	0.2	0.2	0.2

Robust standard errors in italics
* significant at 10%; ** significant at 5%; *** significant at 1%

Appendix C-Unit Root Tests

The following tables report the findings from our unit root tests. We first employ the Dickey-Fuller methodology and then turn to the Hadri-type test as a check. While the results from both tests suggest there are no unit roots in our series, it should be noted that we had to significantly reduce our sample in order to obtain a balanced panel with which to employ the Hadri method.

Table C1. Fisher-type unit-root test

Series: Price Dispersion-White Maize	Statistic		P-Value
Inverse chi-squared(868)	P	4897.739	0.000
Inverse normal	Z	-43.8481	0.000
Inverse logit t(2164)	L*	-61.1553	0.000
Modified inv. chi-squared	Pm	96.7168	0.000
Series: Price Dispersion-Common Beans			
Inverse chi-squared(858)	P	4454.825	0.000
Inverse normal	Z	-42.2477	0.000
Inverse logit t(2069)	L*	-56.9779	0.000
Modified inv. chi-squared	Pm	86.8282	0.000

Ho: All panels contain unit roots   Number of panels = 442
Ha: At least one panel is stationary   Avg. number of periods = 102.74

AR parameter: Panel-specific   Asymptotics: T -> Infinity
Panel means: Included
Time trend: Not included
Drift term: Not included   ADF regressions: 2 lags

The Following reports the Hadri-type specification.

Table C2. Hadri LM Type Unit-Root Test

Series: Price Dispersion-Common Beans		Statistic	P-Value	# of Panels	# of Periods
	Z	**0.7467**	**0.2276**	**3**	**108**

Ho: All panels are stationary
Ha: Some panels contain unit roots

Time trend: Not included Asymptotics: T, N -> Infinity
Heteroskedasticity: Not robust sequentially
LR variance: (not used)

Appendix D- Travel Costs and Constrained Sample Years

The "Law of One Price" stipulates that the prices dispersion of homogeneous goods be driven to the transfer cost between the two points of sale in order to obtain an efficient outcome. Transfer costs therefore form an important component of any analysis of price dispersion and spatial efficiency.

While we would like to include such a measure for all observations in our sample, we were only able to obtain estimates for a small sub-sample of years. Using data and methods obtained from Cirera and Arndt (2008), we generate estimated transfer costs (meticals/kilo) for the markets in our sample.

Estimating the basic specification using only a small sub-sample of years, however, removes a significant portion of our data, and we find that we are unable to obtain any significant findings. Table AD re-estimates Table 7 from above, where we augment the specification in Column 5 to include our transfer cost estimates.

Looking at the results presented in Table D, we find that the coefficients on our cell phone dummy remains negative, however our point estimates are greatly reduced and we obtain no significant results—Columns 1, 2, 4, & 5, for instance, find an *insignificant* effect of treatment within our limited sample. Looking at Column 3, however, we find a significant positive coefficient on our estimated transfer costs (as expected) and a negative and significant effect of mobile phones. Given these results, we conclude that while we lose some degree of accuracy by omitting transfer costs from the results in Section III, we are likely to be *underestimating* the actual effect of cell coverage reported in the main body of this thesis, whereby the resulting bias, if anything, is likely to make our estimates more conservative.

Appendix D. Estimated Impact of Cell Phone Rollout on Price Dispersion (Common Beans) ONLY FOR YEARS 2001-2005

Dependent Variable ($Price_{it}$-$Price_{kt}$)	(1) No Time trend w/ Quarterly Dum-mies	(2) OLS w/ Market-Specific Fixed-Effects	(3) OLS w/ Market-Specific Fixed-Effects & Est. Trans. Costs	(4) Fixed-Effects w/ Market-Pair Fixed-Effects	(5) Variable for one market covered
Cell Phone Dummy (both covered)	-0.33	-0.33	-0.84**	-0.38	-0.01
	0.42	0.42	0.41	0.39	0.73
Est. Transfer Costs			1.66586***		
			0.47964		
Cell Phone Dummy (one covered)					0.27695
					0.61105
Drought Year Dummy		1.42233	3.32***	1.62554***	1.53
		1.32192	0.67	0.5244	1.28
Constant	6.94791***	5.53***	3.23***	5.75***	5.38***
	1.06915	0.8	0.96	0.62	0.8
Quarterly Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Market-Specific Fixed Effects	*Yes*	*Yes*	*Yes*	*No*	*Yes*
Sub-Sample	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*
Observations	1999	1999	1707	1999	1999
Adjusted R-squared	0.37	0.37	0.47	-	0.37
Number of Groups	-	-	-	65	-

Robust standard errors in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Appendix E—Northern Markets

In line with the discussion above, we report the estimates from Tables 7-10 in the main body of the text using the northern markets sub-sample of our data. As indicated, not only are our point estimates close to zero in magnitude in most cases, but we find no significant effect of treatment. These results enforce the discussion that follows our empirical results and indicates that additional factors—such as trade discontinuities, are likely at the heart of market inefficiencies in these regions.

Table E1 (corresponds with Table 7 in the main text). Estimated Impact of Cell Phone Rollout on Price Dispersion (Common Beans)--Average Treatment Effects

	(1)	(2)	(3)	(4)
Dependent Variable ($Price_{it}$-$Price_{kt}$)	No Time trend w/ Quarterly Dummies	OLS w/ Market-Specific Fixed-Effects	Fixed-Effects w/ Market-Pair Fixed-Effects	Variable for one market covered
Cell Phone Dummy (both covered)	0.16	0.16	0	0.21
	0.74	*0.74*	*0.78*	*1.03*
Cell Phone Dummy (one covered)				0.05977
				0.51464
Constant	5.36638***	5.44***	6.59***	5.39***
	0.64844	*0.68*	*0.91*	*0.88*
Drought Year Dummy		-0.07024	-1.96713***	-0.07
		0.56913	*0.65001*	*0.57*
Quarterly Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*
Market-Specific Fixed Effects	*Yes*	*Yes*	*No*	*Yes*
Sub-Sample	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*
Observations	9083	9083	9083	9083
Adjusted R-squared	0.2	0.2	-	0.2
Number of Groups	-	-	103	-

Robust standard errors in italics

* significant at 10%; ** significant at 5%; *** significant at 1%

Table E2 (corresponds to Table 8 in the main text). Effect of Cell Phone Rollout on Price Dispersion-Heterogeneous Effects

Dependent Variable (Pit-Pij)	(1) Basic Specification	(2) Time Dummies	(3) Distance Dummies	(4) Market Sizes	(5) Network Effects-Teledensity	(6) Network Effects-Total # of Mrkts Covered	(7) Coverage Density
Cell Phone Dummy (both covered)	0.16	0.22	2.88		-0.29	1.06	
	0.74	*0.86*	*2.13*		*0.67*	*7.67*	
Cell Phone Dummy * Shrt time. Dummy (<3 hrs)		-0.70648					
		0.64663					
Cell Phone Dummy * Med time. Dummy (3-6 hrs)		0.04					
		0.78					
Cell Phone Dummy * Long time. Dummy (6-12 hrs)		-0.13					
		0.67					
Cell Phone Dummy * Long Distance Dummy (500-1000km)			-2.83752				
			1.97626				
Coverage Density (25km radius)							4.42*
							2.61
Cell Phone Dummy *ln(tot. mrkts covered)						-0.33419	
						3.04432	
Cell Phone Dummy *ln(teledensity)					-0.71967*		
					0.40949		
Cell*Mkt Size Dummy (both major)				Omitted			
				--			
Cell*Mkt Size Dummy (one major)				-0.38308			
				0.9191			
Cell*Mkt Size Dummy (both minor)				0.3			
				0.77			
Cell Phone Dummy * Med. Distance Dummy (150-500km)			-2.73				
			2.07				
Cell Phone Dummy * Short Distance Dummy (<150km)			Omitted				
			--				
Constant	5.44***	5.46***	5.41***	5.45***	16.32***	5.44***	5.10***
	0.68	*0.67*	*0.67*	*0.67*	*1.9*	*0.68*	*0.55*
Drought Year Dummy	-0.07024	-0.08	-0.01	-0.06	0.36	-0.08	0.06912
	0.56913	*0.57*	*0.57*	*0.57*	*1.35*	*0.59*	*0.59648*
Quarterly Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Market-Specific Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Sub-Sample	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*
Observations	9083	9083	9083	9083	6467	9083	9083
Adjusted R-squared	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Robust standard errors in italics

* significant at 10%; ** significant at 5%; *** significant at 1%

Table E3 (Corresponds to Table 9 in the main text)—Effect of Cell Phone Rollout on Price Dispersion- Temporal Effects

Dependent Variable ($Price_{it}$-$Price_{kt}$)	(1) Basic Specification	(2) Temporal Effects-Cell Coverage over Time	(3) OLS w/ Lagged Dependent Variable	(4) A-Bond Estimator
Cell Phone Dummy (both covered)	0.16	0.43	0.04	-0.42
	0.74	*2.25*	*0.43*	*0.71*
Cell Phone Dumm* quartly time trend		-0.00448		
		0.04124		
Lagged Dependent Variable (1 period lag)-Common Beans			0.46938***	
			0.02055	
Constant	5.44***	5.43***	4.71***	
	0.68	*0.66*	*0.73*	
Drought Year Dummy	-0.07024	-0.07	-1.60*	2.13461
	0.56913	*0.58*	*0.81*	*1.95084*
Quarterly Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*
Market-Specific Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*
Sub-Sample	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*
Observations	9083	9083	7973	12468
Adjusted R-squared	0.2	0.2	0.39	-
Number of Groups	-	-	-	188

Robust standard errors in italics

* significant at 10%; ** significant at 5%; *** significant at 1%

Table E4 (Corresponds to Table 10 in the main text)—Effect of Cell Phone Rollout on Price Dispersion-Additional Crops

Dependent Variable ($Price_{it}$-$Price_{kt}$)	(1) Common Beans	(2) Lrg. Groundnuts	(3) White Maize	(4) Rice	(5) Wheat Flour
Cell Phone Dummy (both covered)	0.16	-5.18	-0.01	0.63**	-0.46*
	0.74	*9.7*	*0.06*	*0.25*	*0.26*
Drought Year Dummy	-0.07024	-1.20901	2.13961***	0.20177	1.4779
	0.56913	*4.91936*	*0.32241*	*0.23899*	*0.95152*
Constant	5.44***	7.93	1.36***	2.73***	1.76*
	0.68	*5.44*	*0.08*	*0.31*	*0.91*
Quarterly Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Market-Specific Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Sub-Sample	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*	*Southern Mkts*
Observations	9083	5137	8226	9101	5211
Adjusted R-squared	0.2	0.08	0.24	0.17	0.16

Robust standard errors in italics

* significant at 10%; ** significant at 5%; *** significant at 1%

Appendix F—Description of the Variables

The following section outlines the primary variables used for estimation, as well as a discussion on their potential effects.

Dependent Variable

In keeping with our motivation to evaluate market efficiency as determined by the “Law of One Price,” the dependent variable in this study is the absolute value of the price difference between markets *i* and *k* for a given time period (month) t:

$$dprice_{ik,t} = |P_{i,t} - P_{k,t}| \quad \text{for } i \neq k$$

Although several measures of price dispersion are used in the literature (for example, the min/max of prices across markets, the sample variance of prices across markets over time, and the Coefficient of Variation across markets in a given period), the use of the absolute difference in prices between market pairs is consistent with other studies that look at similar market types. Aker (2010), for instances, cites the large distances between markets in Niger as the motivation for using absolute price differences in her model, and given the similarity between the markets in her study and those in Mozambique, we find it appropriate to carry over this methodology.

Variables that Effect Spatial Price Dispersion

The following section outlines and defines a series of variables that are shown to effect spatial price dispersion among markets. Inclusion of these variables in our models can be justified at the intuitive, theoretical, and empirical level, and are widely recognized by the literature as being significant explanators of spatial price dispersion:

1) *Transportation Costs*—The "Law of One Price" states that in an efficient setting, identical goods will have the same price in all locations net of the transportation costs associated with arbitrage. Given that this study is aimed at quantifying the role information plays in obtaining spatial efficiency, including accurate measures of transportation costs is paramount to creating viable estimates of our parameters of interest. Unfortunately we are unable to obtain accurate data for all observations in our sample, and hence opt not to use such a variable in the main body of this thesis. See Appendix D for more details.
2) *Drought year dummies*—Since we are evaluating agricultural prices, it is important to consider explanators that might adversely impact the supply of crops. Climatic variables are therefore necessary to capture the effects of these adverse shocks on crop output.

Cell Phone Coverage Variables

The estimated impact of mobile telephony remains the primary parameter of interest for this empirical study. Given this objective, there are several possible measurements of cell phone coverage that will be employed in the final models:

1. *Cell Phone Dummy, both markets covered (a.k.a bothcov)*— a dummy variable equal to 1 if both markets *i* and *k* have a cell tower present in time *t*, and 0 otherwise.

a. This is the primary variable of interest and directly measures the resulting change in price dispersion once cellular technology is made available to both markets in a pair (net of all the other included and relevant explanatory variables). *A priori*, I expect the coefficient on *bothcov* to be negative and significant, as increased access to market information as generated through cell phone use will enable arbitrage activity and shift markets towards a more integrated equilibrium.

2. *Cell Phone Coverage Dummy, one market covered (a.ka. onecov)*—dummy variable equal to 1 if only one market in a market pair has a cell tower at time *t*.

a. The interpretation of the magnitude and sign of this coefficient is open to speculation, however overall I expect the coefficient to be *insignificant*. Consider three markets: A, B, and C—at time *t*, markets A and B have a cell tower, but C does not (i.e. $cellcov_{A,B} = 1$ and $cellcov_{A,C} = 0$, $onecov_{A,C} = 1$). Imagine you are a trader in Market B, and you are considering arbitraging between your present location and Market A or C. Standing in Market B, it stands to reason that you could use a cell phone to determine the price in Market A, but not in Market C. Given the uncertainty, you might be tempted to refrain from interaction with Market C (with an unknown price) and instead trade with Market A (contingent, of course, on there being an attractive trade to be made). Such a pattern would lead trade between markets pairs where *onecov* = 1 to diminish relative to where *bothcov* = 1, leading there to be an insignificant effect of cell phones on price dispersion.

b. On the other hand, it could be the case that you have a contact who happened to pass through Market C yesterday, and is now within cell service and calls you to report yesterday's prices. In this case, information *is* being transferred between markets (albeit slightly outdated) and there may in fact be some effect of cell phones on prices even if only one of the markets has a cell tower. The likelihood of such an occurrence is certainly unknown, and without more insight into the workings of these markets it would be hard to presume beforehand. In addition, the overall increased access to cell phones throughout the country might create trends in price behavior that come as a secondary effect of mobile phones—that is, perhaps the changes in price behavior that result from some market pairs being connected via cell phones (i.e. *bothcov* = 1) will spill over into market pairs that don't have mobile coverage through other channels, such as by word of mouth. Intuitively, I suspect that the effects of *onecov* will be insignificant, however the discussion above presents the possibility that network effects and unobserved patterns in information flows might be captured through the *onecov* variable.

3. *Coverage Density (25km radius)*—the percentage of the area within 25km of a market that has cell phone coverage. These figured are calculated on an annual basis as more and more towers were introduced throughout Mozambique.
    a. The dummy variables outlined above (*onecov* and *bothcov*) are beneficial to our analysis insofar as they proxy for whether information is available to traders to commit arbitrage between the various markets in our study. However, the *onecov* and *bothcov* dummies only account for the presence of a cell tower within the physical market center, and do not account for whether mobile service is available

to famers who live outside a market area, but that nonetheless rely on these centers to sell their goods. If we remain interested in how cell phones affect the economic lives of the poor within these areas, this remains a relevant question. Consider, for example, the typical smallholder farmer who has relies on local markets to sell their goods. Without access to market information, they must make their decisions on which market to attend at random or via historical information (i.e. a lagged dependent variable). However if they have cell service, then they have the ability to call several markets—or likewise several intermediaries—to determine the best price. This *coverage density* variable is an attempt to capture this phenomenon—using a "specified market area" of 25km, I expect to find that market areas with more cell coverage will have overall lower price dispersion—given that our underlying hypothesis is based on the notion that cell phones are lowering search costs (and consequently that farmers have multiple markets from which to plausibly choose), *I expect that this variable will be especially relevant for markets that are closer together*.

4. *teledensity*—this is a macro-level variable that gives the total penetration rate for cell phones within Mozambique each year. These data are measured as the "number of mobile subscriptions per 100 in the population" and come from the International Telecommunications Database through the United Nations. An important caveat in these figures is that they may inaccurately represent the "true" magnitude of teledensity. First, because this figure reports subscriptions, it may inaccurately represent the number of users who obtain multiple accounts through the use of pre-paid cards. Second, while it measures the

overall number of subscriptions, it doesn't take into account shared-phones and the overall percentage of the population with *access* to mobile phone service.

Appendix G—Cross Section of Agricultural Prices

The following section attempts to provide some insight and context into the pricing behavior of agricultural goods in our study. As the empirical results suggest, we find a relatively weak effect of mobile phones on price dispersion—the following charts and tables attempt to provide a "birds-eye" view of the agricultural markets in question, and affords us the opportunity to visualize the data behind the regression results. Overall, we find that the price behavior of crops, at least upon visual inspection, remains relatively stable over time, and if anything, appears to increase in the later sections of our sample period. While these charts do not constitute rigorous analysis, they provide a helpful complement to the empirical sections above.

Figure 9 demonstrates the overall price level (adjusted for inflation) for several key goods within the *SIMA* database. Overall, we observe that prices remain relatively stable across time with expected seasonal variation.

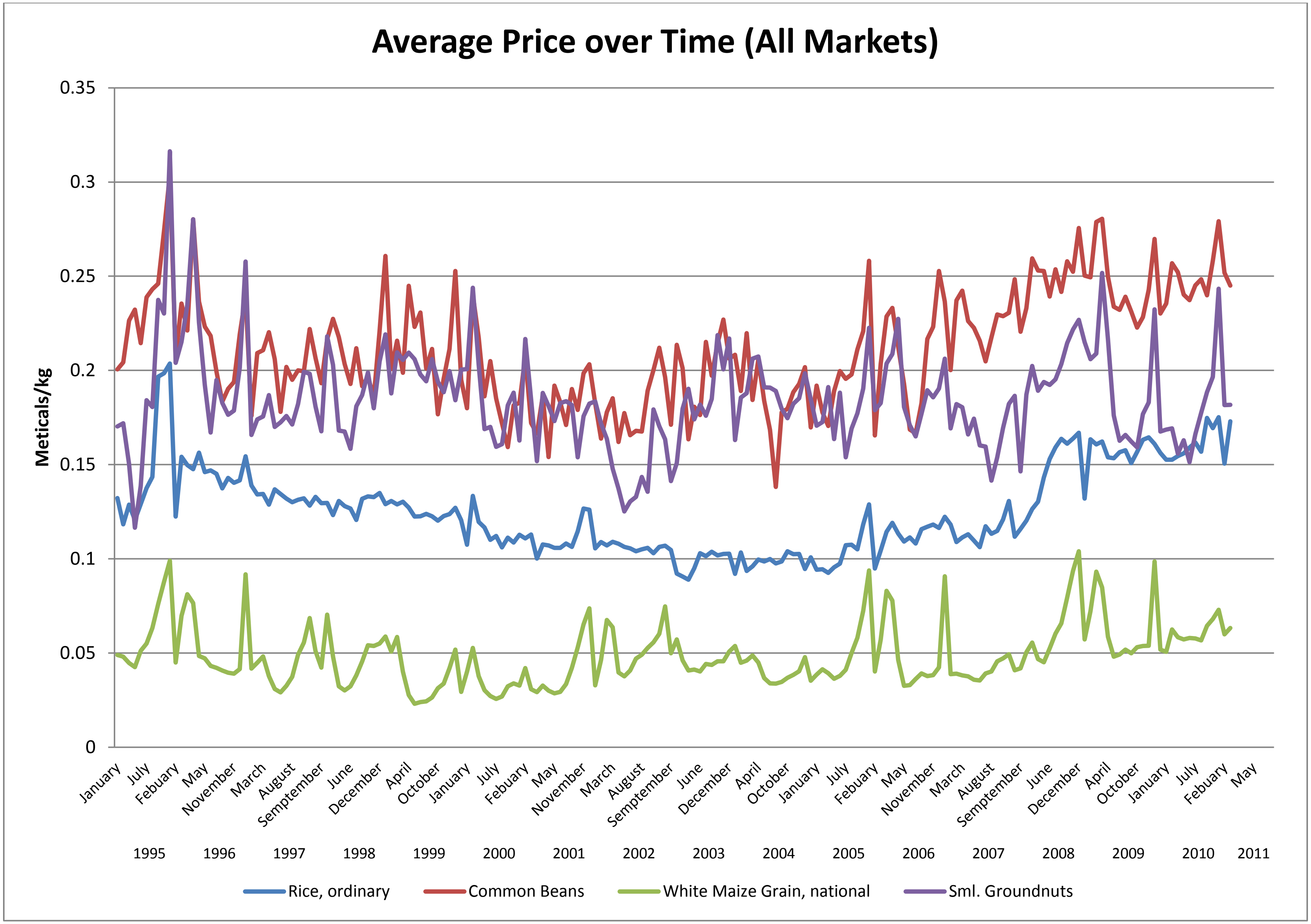

Figure 9. Average Crop Prices. Source *SIMA* 2011.

We can further refine the this visual interpretation by considering price behavior not in terms of linear time, but rather by adjusting based relative time since a market pair receives a mobile phone. Figure 10 displays the overall average prices for each market, where month "0" is interpreted as the first month a mobile tower was introduced.[12]

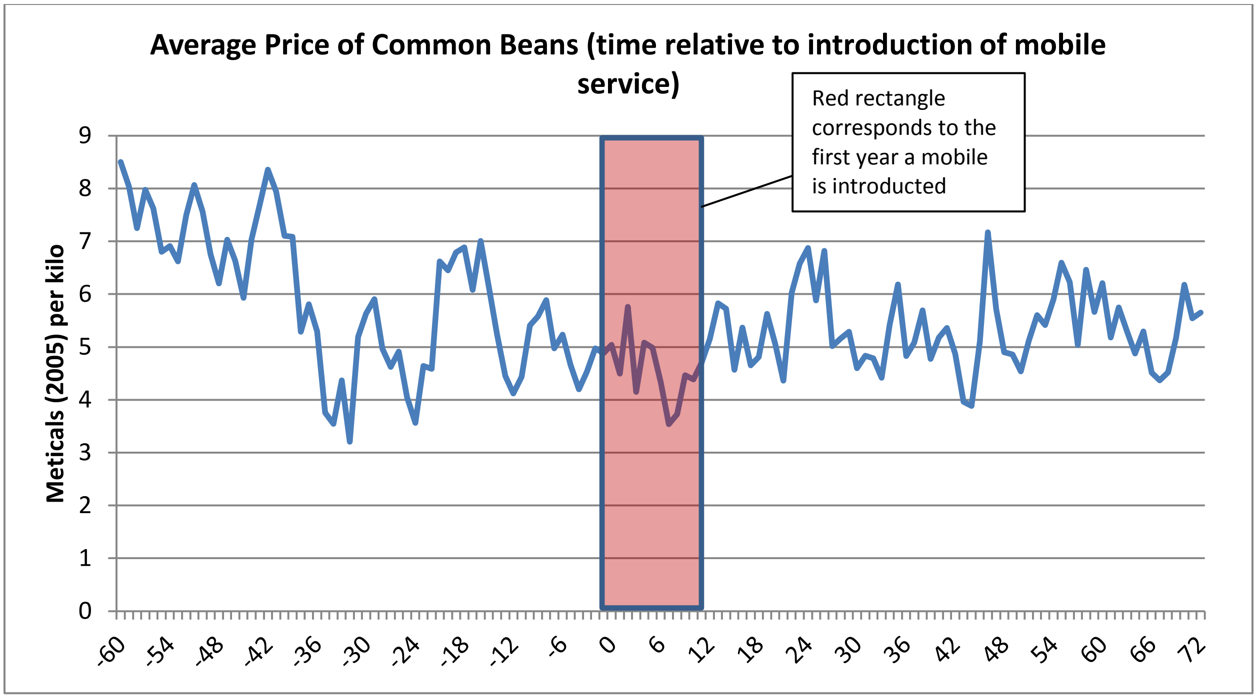

Figure 10. Source: SIMA 2011

Again, we find that the overall price level remains relatively consistent in the periods immediately before and after the introduction of cell phones, indicating little or no response to treatment.

[12] Note: Because our data on cell tower construction is annual, we cannot determine the month in which a tower is built. Consequently, we should take caution when we interpret graphs that compare monthly price data with annual treatment data. For this reason, we include red rectangle seen in Figures 10 & 12.

We continue this line of analysis by turning to price dispersion rather that the overall level of prices:

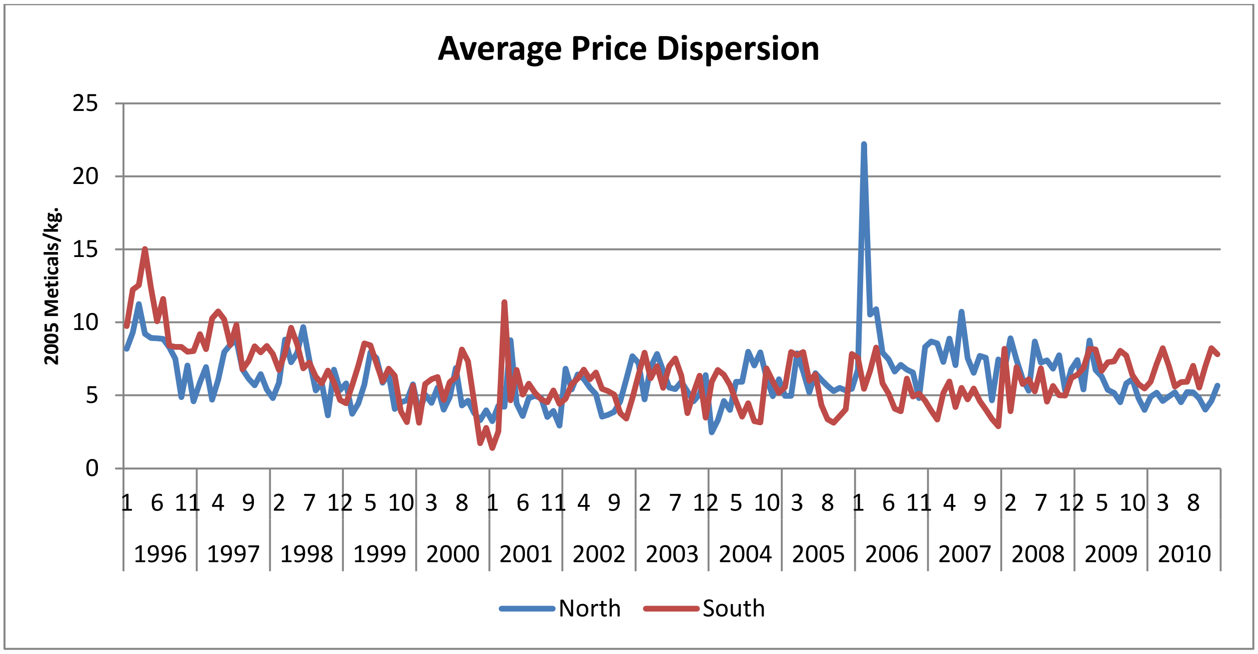

Figure 11. Source: SIMA 2011

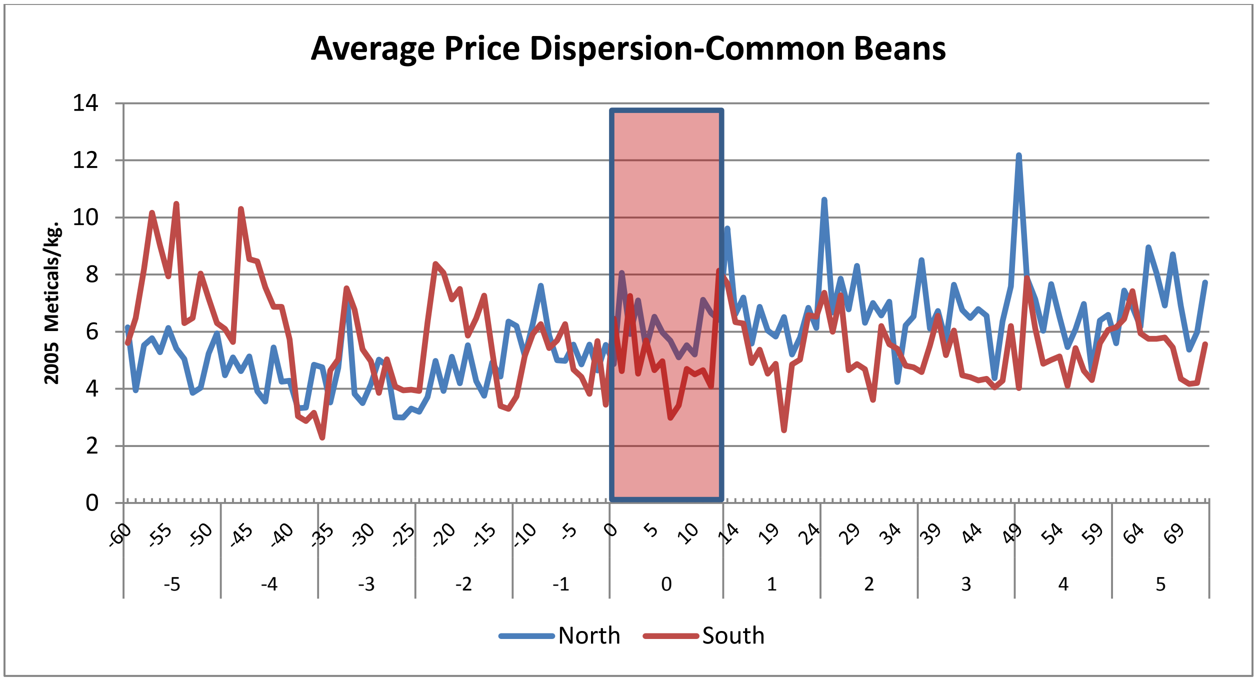

Figure 12. Source: SIMA 2011

Again, using simple visual inspection, we see little effect of mobile phone rollout on price dispersion.