The Power of Information: The ICT Revolution in Agricultural Development

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Abstract

We review the state of information and communication technologies (ICTs) and their impact on agricultural development in developing countries, documenting the rapid changes that have taken place over the past decade. Although there remains a wide gap in access between rural and urban areas, the spread of mobile phones in rural areas has led to important changes in the agricultural sector. We find that access to mobile phones has generally improved agricultural market performance at the macro level; however, impacts at the micro level are mixed. Evidence regarding the impact of market information systems (MIS) delivered through mobile phones on farm prices and income is limited, but the evidence points to strong, heterogeneous impacts. Similarly, the rollout of extension programs though ICTs is still in an early stage, and little research is available regarding such programs' impacts.

1. INTRODUCTION

Developing countries' agricultural sectors typically consist mainly of small farmers with poor access to physical infrastructure and market and extension information. These farmers face both high transaction costs and constraints on information that limit optimal production and marketing choices. Information and communication technologies (ICTs) have significant potential to overcome these deficiencies by providing cost-effective communication that allows farmers to take advantage of previously untapped trade opportunities and to learn about previously unknown innovative practices. ICTs have expanded rapidly in developing countries in the past decade, and as a result, there is significant interest in better understanding how these technologies affect rural and agricultural households' livelihoods, as well as how to better target efforts to use these tools most effectively.

Two main difficulties exist in the analysis of the impact of ICTs on agricultural development. First, ICTs affect a wide array of outcomes in addition to agriculture; because ICTs enhance economic opportunities in a wide variety of ways, they also have sizeable macroeconomic impacts (Roller & Waverman 2001, Torero et al. 2006, Gruber & Koutroumpis 2011). Second, ICTs encompass many different types of technologies, from computers and the Internet to radio and television to mobile phones, to name just a few. Thus, the impact of ICTs varies widely depending on which specific technology is used.

Currently, most ICT projects in developing countries are deployed for two main purposes. The first is to examine the impact of ICTs on market price information. In many cases, farmers in rural areas are not well informed about prevailing market prices (Mitra & Sarkar 2003, Fafchamps & Hill 2008). Therefore, they may not sell their products in the most profitable markets or may accept lower prices from middlemen, leading to the misallocation of resources and inefficiencies in the agricultural supply chain. The second purpose is to examine the role of ICTs as a means to enhance farmers' knowledge about improved agricultural practices and technologies. Given the high cost of traditional extension services, ICTs may be a more effective way to increase farmers' awareness of improved practices and therefore agricultural productivity. We restrict our review mainly to mobile phones because they are more widespread than other forms of ICTs.

This article has three parts. First, we analyze the extent of the ICT and mobile phone revolution in developing countries' rural and agricultural areas. Second, we give a comprehensive overview of the conceptual framework for ICT analysis. Third, we review the available evidence regarding the impacts of ICT and mobile phone access, market information systems (MIS), and extension advice delivered through ICTs on agricultural development. On the basis of this analysis, we then highlight some gaps to be addressed in future research.

2. THE MOBILE PHONE REVOLUTION IN DEVELOPING COUNTRIES

2.1. Penetration of Mobile Phones into Rural Areas

Until the 1990s, landline telephones were the predominant form of communication; however, they were not accessible to significant proportions of the population in developing countries, in part due to higher costs.[1] Thus, it is not surprising that the number of landlines per inhabitant has either

[1]For example, Roller et al. (2005) find that the per-connection cost of a mobile network is 50% lower than that of a landline system. Furthermore, Aker & Mbiti (2010) show that Kenyan firms had to wait, on average, 100 days to get a landline and that this process usually required a bribe.

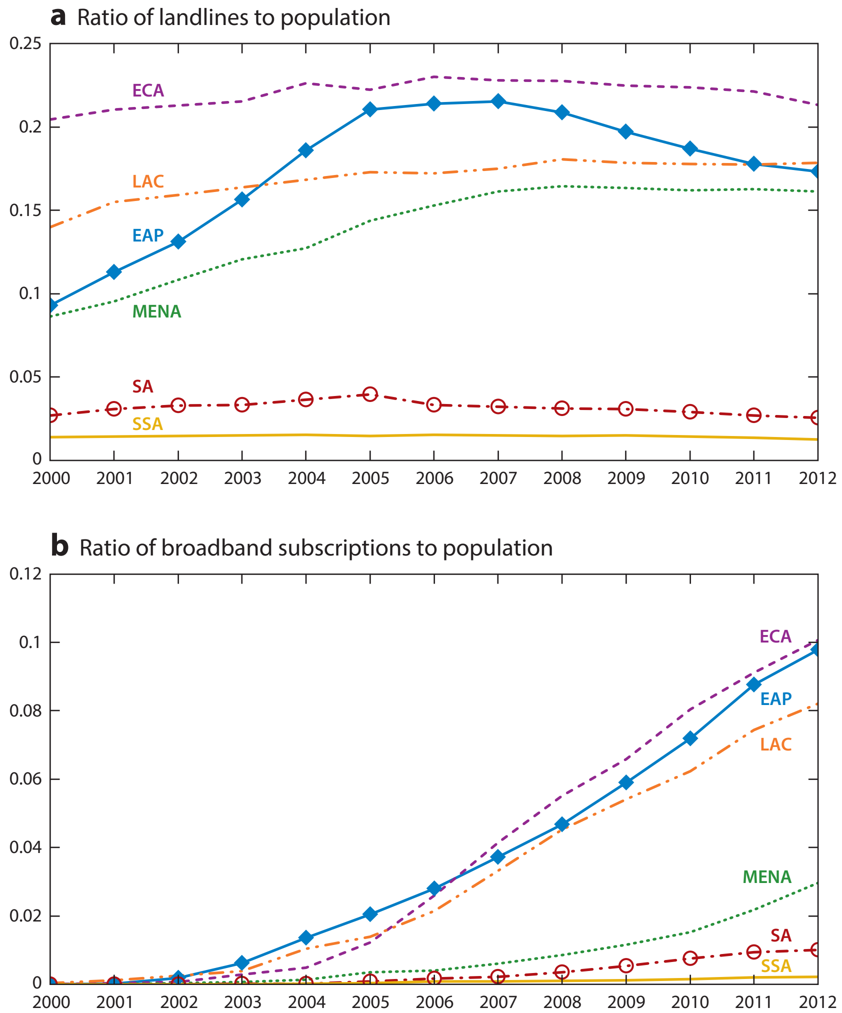

Figure 1

Penetration rates (2000–2012) of (*a*) landlines and (*b*) Internet broadband subscriptions in developing countries, by region. Abbreviations: EAP, East Asia and Pacific; ECA, Europe and Central Asia; LAC, Latin America and the Caribbean; MENA, Middle East and North Africa; SA, South Asia; SSA, sub-Saharan Africa. High-income (OECD and non-OECD) countries are excluded from the sample. Data from International Telecommunication Union (ITU) (mobile phone subscriptions) (**http://tinyurl.com/poehsmu**) and World Bank (country categories) (**http://tinyurl.com/346ptef**; accessed December 10, 2013).

decreased or stagnated in most developing countries (**Figure 1**). As of 2012,[2] there were only 0.11 landlines per inhabitant in developing countries. By comparison, ICTs showed considerable expansion from 2000 to 2012: The ratio of broadband subscriptions to population reached 0.1

[2]Information is based on the International Communications Union's (ITU's) statistics (**http://tinyurl.com/poehsmu**). We follow the World Bank's country classification to separate developed countries from developing countries (**http://tinyurl.com/346ptef**). Our definition of developing countries excludes all high-income (OECD and non-OECD) nations.

in Europe, Central Asia, East Asia, and the Pacific but was less than 0.03 in the Middle East, Northern Africa, and sub-Saharan Africa (**Figure 1**). However, overall, the Internet reaches only a modest proportion of developing countries' populations, with only 0.05 broadband subscriptions per inhabitant.

In contrast, the penetration rate of mobile phones in developing countries—i.e., the ratio of mobile phone subscriptions to population—expanded dramatically over the past 10 years (see **Figure 2**). By 2012, in Europe, Central Asia, Latin America, and the Caribbean, there were more mobile connections than people; sub-Saharan Africa and South Asia also saw dramatically increased phone subscriptions. However, the penetration rate as calculated above may exaggerate actual access: Households may have different phones or SIM cards that are double counted in this ratio (leading to ratios that exceed 1). For example, a recent study finds that mobile phone users in developing countries own 2.2 SIM cards on average (The Economist 2012). In any case, the changes in ICT use in developing countries over the past decade have been significant.

To better understand mobile phone penetration in rural and agricultural areas, we analyze large-scale, representative household surveys in a number of developing countries. **Table 1** presents the percentage of urban and rural households that own a mobile phone in 25 countries in Latin America, Asia, and Africa. As **Table 1** shows, ownership of mobile phones varies considerably between countries, being generally higher in Latin America and Asia than in Africa. Whereas more than 80% of households own a mobile phone in Colombia, less than 40% do in Malawi and Mozambique; in Ethiopia, this figure drops to less than 25%. In contrast, some African countries have surprisingly good access, such as Senegal (88%) and Nigeria (71%). There are also wide gaps in mobile phone ownership between rural and urban areas; overall, rural areas have less ownership. This gap is again generally smaller for Latin America and Asia than it is for Africa.

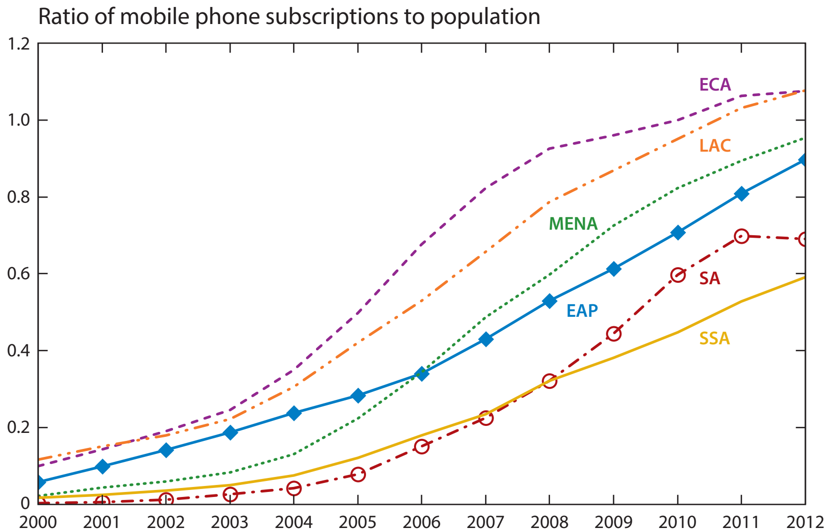

Figure 2

Penetration rates (2000–2012) of mobile phones in developing countries, by region. Abbreviations: EAP, East Asia and Pacific; ECA, Europe and Central Asia; LAC, Latin America and the Caribbean; MENA, Middle East and North Africa; SA, South Asia; SSA, sub-Saharan Africa. High-income (OECD and non-OECD) countries are excluded from the sample. Data from International Telecommunication Union (ITU) (mobile phone subscriptions) (**http://tinyurl.com/poehsmu**) and World Bank (country categories) (**http://tinyurl.com/346ptef**; accessed December 10, 2013).

Table 1 Percentage of households that own a mobile phone, by residence area (selected countries, circa 2010)

	Urban (%)	Rural (%)	Rural-urban gap (%)	All (%)
Latin America				
Bolivia (2007)[a]	77.6%	18.7%	58.9%	57.0%
Brazil (2009)[a]	83.3%	53.2%	30.1%	78.8%
Colombia (2010)[a]	90.2%	71.7%	18.5%	86.0%
Ecuador (2010)[a]	82.9%	59.7%	23.2%	75.5%
Mexico (2007)[a]	66.6%	45.0%	21.6%	55.2%
Peru (2010)[a]	82.2%	47.1%	35.1%	70.4%
Asia				
India (2011)[b]	76.0%	51.2%	24.8%	59.2%
Bangladesh (2010)[c]	82.7%	56.8%	25.9%	63.7%
Nepal (2011)[p]	91.6%	71.9%	19.7%	74.7%
Cambodia (2010)[s]	90.1%	56.2%	33.9%	61.9%
China (2010)[t]	76.3%	60.7%	15.6%	67.9%
Africa				
Tanzania (2010)[d]	77.5%	34.2%	43.3%	45.4%
Kenya (2010)[e]	71.9%	55.0%	16.9%	59.8%
South Africa (2008–2009)[f]	87.5%	82.0%	5.5%	85.7%
Liberia (2009)[g]	69.0%	20.7%	48.3%	43.2%
Malawi (2010)[h]	72.7%	32.3%	40.5%	39.0%
Ghana (2010)[i]	63.4%	29.6%	33.8%	47.7%
Nigeria (2009)[j]	88.3%	60.3%	28.0%	70.6%
Egypt (2008)[k]	54.1%	27.8%	26.3%	40.5%
Ethiopia (2011)[l]	65.2%	12.8%	52.4%	24.7%
Uganda (2011)[m]	86.8%	53.1%	33.7%	59.4%
Senegal (2011)[n]	95.4%	81.7%	13.7%	88.4%
Mozambique (2011)[o]	66.8%	20.0%	46.8%	34.1%
Zimbabwe (2011)[q]	90.1%	48.0%	42.1%	62.2%
Rwanda (2010)[r]	71.8%	35.1%	36.7%	40.3%

[a]From OSILAC (**http://www.eclac.org/tic/flash/**). Data are based on different household surveys. When multiple years of data were available, we took the most recent survey. [b]From Census of India (**http://tinyurl.com/kej98a8**). [c]From Islam & Saha (2011), based on the 2010 Household Income and Expenditure Survey. [d]Mainland Tanzania only (excludes Zanzibar). From Tanzanian National Bureau of Statistics, based on the

(*Footnotes continued*)

2.2. The Use of Mobile Phones for Agricultural Development

There are many reasons to believe that mobile phones may have a large impact on agricultural markets. Mobile phones can allow different market agents to communicate more efficiently, thus enhancing information flows and potentially increasing efficiency. These results can be critically important for rural areas in developing countries, where inadequate infrastructure tends to make markets less integrated. In this section, we review the way in which mobile phones are being used for agricultural development.

2.2.1. Agricultural trade. As mobile phones have spread rapidly in developing countries, researchers have begun to look at the implications of increased phone coverage and ownership for agricultural markets, given the presumed importance of improved information for such markets (e.g., Jensen 2007, Lee & Bellemare 2013, Aker & Fafchamps 2014). However, few surveys look at how farmers and traders actually use their phones in agricultural marketing activities. Exceptions include Reardon et al. (2012), who collect data in China, Bangladesh, and India on farmers' phone use for marketing transactions in major commercial rice- and potato-producing areas, and Minten et al. (2013), who collect information on phone use for transactions with teff, a major commercial crop in Ethiopia.

A large proportion of the farmers interviewed in these areas, ranging from a high of 97% in China to a low of 27% in Ethiopia, owned mobile phones at the time of the survey (**Table 2**). However, only between 12% and 78% of farmers were in phone contact with the buyer in their last marketing transaction before the sale. Thus, the use of mobile phones for market transactions, although high, is still significantly lower than would be expected from overall phone ownership. This discrepancy seems partly driven by a lack of perceived benefits: The prevalence of auction systems and of government rice procurement price setting in some areas of China and India seems to lower the potential advantages of mobile phone use. In situations in which farmers see clearer benefits, phone contacts are more prevalent. For example, phones are actively used in the potato trade in India, where most of the marketing transactions are done off market and near cold stores (Reardon et al. 2012).

On the basis of a simple average of products and countries in Asia, the data show that almost a quarter of farmers in commercial zones reached a price agreement by phone in their last transaction. For rice and potato supply chains in Dhaka, for rice chains in Beijing, and for potato chains in Delhi, almost all farmers who used phones contacted multiple traders before engaging in a transaction. Overall, 40% of staple suppliers in these rural-urban supply chains contacted multiple buyers by phone before their last transaction. This finding illustrates the extent to which access to phones is empowering farmers and changing marketing systems in developing countries. The low numbers seen in Ethiopia also illustrate the large variations between

Table 1 (*Footnotes continued*)

2010 Demographic and Health Survey. [e]From Kenya National Bureau of Statistics, based on the 2010 National ICT Survey. [f]Percentage of households that either own or have access to a mobile phone. From Statistics South Africa (2011), based on the 2008–2009 Living Conditions Survey. [g]From Liberia Malaria Survey Indicator 2009. [h]From Malawi Demographic and Health Survey 2010. [i]Percentage of the population 12 years or older possessing mobile phones. From 2010 Population and Housing Census. [j]From Nigerian Communications Commission, Central Bank of Nigeria, National Bureau of Statistics, and 2009 Collaborative Survey on Socio-Economic Activities in Nigeria. [k]From 2008 Demographic and Health Survey. [l]From 2011 Demographic and Health Survey. [m]From 2011 Demographic and Health Survey. [n]From 2010–2011 Demographic and Health Survey. [o]From Inquérito Demográfico e de Saúde 2011. [p]From 2011 Demographic and Health Survey. [q]From 2010–2011 Demographic and Health Survey. [r]From 2010 Demographic and Health Survey. [s]From 2010 Demographic and Health Survey. [t]Percentage of households with access to mobile phones according to the 2010 China Family Panel Survey.

Table 2 Ownership and use of mobile phones by commercial farmers in selected developing countries

	Production areas in hinterland of			
	Dhaka	Beijing	Delhi	Addis Ababa
Staple crop	**Rice**	**Rice**	**Rice**	**Teff**
Percent of farmers that own a cell phone	80%	97%	73%	27%
Use of phone in last transaction				
Percent of farmers who were in contact with buyer via phone	71%	47%	19%	12%
If phone was used: percent of farmers who agreed upon the price on the phone	58%	34%	51%	71%
If phone was used: percent of other buyers contacted	90%	95%	50%	—
If phone was used: number of phone calls concerning this transaction	2.5	2.5	2.5	—
Vegetable crop	**Potato**	**Potato**	**Potato**	
Percent of farmers that own a cell phone	82%	92%	97%	
Use of phone in last transaction				
Percent of farmers who were in contact with buyer via phone	31%	19%	78%	
If phone was used: percent of farmers who agreed upon the price on the phone	66%	18%	60%	
If phone was used: percent of other buyers contacted	98%	51%	99%	
If phone was used: number of phone calls concerning this transaction	4.8	3.7	7.6	

Data from Reardon et al. (2012) and Minten et al. (2013). Em dash (—) denotes no data.

countries and indicate that mobile phone penetration with farmers is still in the starting phase in that country.

Despite farmers' low use of mobile phones for commercial transactions in some areas, such as Ethiopia, mobile phones may still have important effects on agricultural marketing systems because of widespread use by agricultural traders. **Figure 3** shows the extent to which mobile phones are used by cereal traders in Ethiopia; the figure shows how mobile phone coverage has changed in the past decade for Ethiopia's major wholesale cereal markets. In 2000, only Addis Ababa, the capital city, had mobile phone coverage; by 2005, there was almost universal coverage of wholesale markets. **Figure 3** further shows that mobile phone usage rates reached 100% of the traders for major cereal markets within an average of only 4–5 years after the introduction of coverage.

Minten et al. (2012) find that nearly half of the traders studied reported having a landline phone at home before gaining access to a mobile phone, indicating that there was not a complete communication void in Ethiopia. Mobile phone technology has, however, improved ease of communication. More than twice as many traders and brokers use their mobile phones today for conveying price information and making deals than did so using landline phones when the latter was all that was available. Because a market's physical location matters less with mobile phone technology, traders and brokers also appear to be increasingly bypassing wholesale markets in rural areas and in urban towns (Minten et al. 2012). Such evidence therefore seems to suggest that

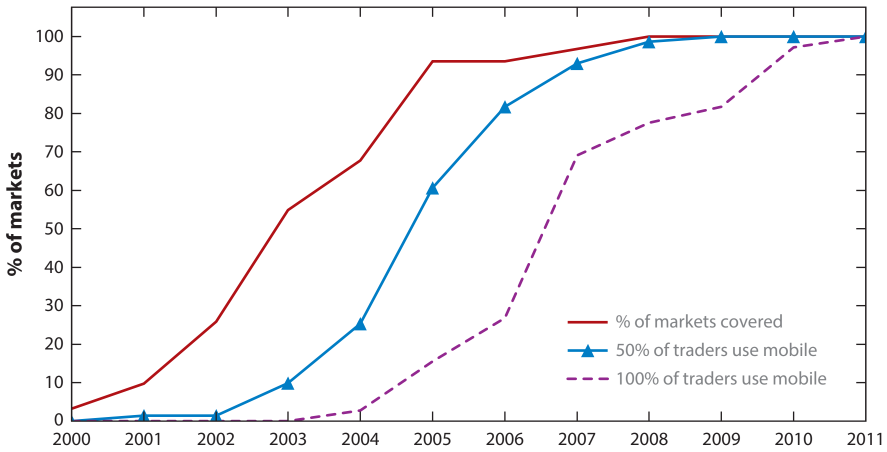

Figure 3

Mobile phone use for business by cereal traders in major wholesale markets in Ethiopia: cumulative percentage, 2000–2011. Data from Minten et al. (2013).

mobile phone use has important implications for the efficiency of agricultural marketing systems in developing countries.

2.2.2. Platforms for agricultural development. A number of service providers have started using ICTs and mobile phones for information platforms for agricultural development in developing countries. The GSM Association's Mobile for Development Intelligence[3] compiles a database of ICT-enabled products and services for development initiatives; as of October 2013, 98 initiatives were listed in the agriculture sector globally. **Table 3** analyzes the 87 of these initiatives that provide direct services to rural populations.[4] Most initiatives deliver information regarding market prices (48%) and agricultural extension (39%), combined in an important number of cases with weather advisory information. Arguably due to their larger availability, mobile phones are used in most of these projects; delivery is done mainly through SMS, although voice messages, interactive voice response systems, or mobile applications are also used. However, a small group of initiatives uses email or the Internet, and increasing Internet access in rural areas will likely lead to an expansion of this delivery channel in the future.

3. CONCEPTUAL FRAMEWORK

In this section, we review different theoretical frameworks that have been used to explain how ICTs can affect agricultural development, focusing on the conveyance of market price information and agricultural technology advice. The overall argument is rather simple: ICTs reduce information costs at various stages of the agricultural value chain; this cost reduction then yields welfare gains. However, the available theoretical models capture this phenomenon in different ways.

[3]See **https://mobiledevelopmentintelligence.com/**.

[4]A complete list of the 87 projects we reviewed is available from the authors upon request.

Table 3 Overview of ICT platforms for agricultural development

Project distribution by delivery channel[a]		Project distribution by type of information[a]	
Mobile phone	81	Market prices	43
SMS/voice message	56	Ag extension	35
Phone call	18	Weather	19
IVR[b]	20	Match supply and demand	17
App[c]	13	Social network	5
Email/Internet	18	Other	15
Radio	1	Total	87
Other	5		
Total	87		

[a]Numbers in columns do not add up to 87 because one project can use multiple delivery mechanisms or provide different types of information.
[b]Denotes interactive voice response.
[c]Includes applications that can be used through either smartphones or basic phones.

3.1. Agricultural Prices

Rural areas in developing countries are more sparsely populated, have poorer infrastructure, and are less connected to markets than areas in developed countries (Dorosh et al. 2010) and are usually hampered by information deficiencies. The effect of ICTs on these informational deficiencies can be modeled through search cost models. A typical simplistic model would be as follows: Suppose that a farmer has the option to sell his harvest in different markets. If he knew the prices in each location, he would simply choose the market where he would make the most profit (net of transportation costs). Traditionally, he might have to visit each market to collect this price information, and his decision to do so would be based on the cost of that search. If the costs were large, he might settle for a lower price rather than exploring alternative opportunities. ICTs can dramatically impact this scenario: Rather than incurring travel costs to gather prices, a farmer can readily find price information through a (much cheaper) phone call or through (even cheaper) SMS. Thus, ICTs' lower search costs can translate into more extensive search behavior and thus better opportunities for farmers. It can be argued that in the long run, if farmers are able to find more profitable opportunities, they can change the allocation of production factors or crop patterns and increase their agricultural productivity.

Aker (2010) applies this same framework to agricultural middlemen (who act as intermediaries between small farmers and wholesale buyers in markets). Assume that the middleman has purchased crops from different farmers in several villages; however, he does not know the prevailing prices that wholesale buyers are paying in different markets. If ICTs reduce the cost of researching alternative prices, he will be able to find better business opportunities. Aker's model also provides some interesting insights into more general equilibrium effects: Traders' higher sales in markets with higher prices imply that ICTs also enhance arbitrage across markets. As supply expands where crops are most valued (and reduces where they are not), there is the potential for much larger welfare gains. The enhancement of market arbitrage can also reduce price variability if ICTs encourage trade between regions; rather than depending solely on regional supply, local prices depend on a more aggregate measure of production. If consumers or farmers are risk averse, there can also be welfare gains from more stable prices through the increasing use of ICTs.

The role of ICTs in more efficient arbitrage across markets is also emphasized by Jensen (2007), whose model looks at traders (fishermen) in two towns. Typically, fishermen sell their daily catch in their own village; however, they can also incur a transportation cost and sell in the other town. If there is any production shock, price differentials should emerge and encourage trade (arbitrage) between towns. Without communication technologies, each fisherman has information only about his own catch, providing him with limited information about aggregate shocks (e.g., high fish density). If his catch is high, he may believe that the fish supply in his own village is high, which will lead to lower local prices (encouraging him to incur the transportation cost and to sell in the other village). However, he cannot fully distinguish these aggregate phenomena from other possible idiosyncratic shocks (e.g., he had a lucky day). Communication technologies would allow him to access prices in both locations. In this model, the introduction of ICTs has large potential implications for overall welfare: From the producer's side, the sum of profits in both villages is higher because of the better opportunities for traders, whereas from the consumers' side, as produce is traded on the market with the higher marginal valuation, aggregate surplus increases.

In Jensen's (2007) model, no price information is systematically available to market participants. By contrast, other researchers argue that agricultural markets in developing countries are characterized mostly by informed parties (usually traders) who have better access to market price information and who leverage this information asymmetry when bargaining with less informed farmers. Svenson & Yanagizawa (2009) model this relationship in a monopolistic screening framework. The farmer establishes an ex ante menu of contracts, to which he supplies different amounts of his harvest, depending on the market price. In this case, the farmer establishes these contracts in such a way that the trader has an incentive to reveal the true market price; if the trader reveals a high market price, the farmer concedes an informational premium through lower farm-gate prices. However, if the trader reveals that the prices are low, the farmer restricts his supply, hurting the trader's profits. Thus, the contract establishes a truth-telling mechanism. In this model, the farmer does find out the prevailing market prices, entailing a loss of efficiency: The farmer has to either receive lower farm-gate prices or restrict his optimal sales quantities.

Fafchamps & Minten (2012) provide an alternative model for this bargaining process. In their setting, an informed trader bilaterally bargains with a risk-averse farmer. The farmer has to decide whether to sell his harvest to the trader or sell it directly in the market, where he is uncertain of the price. Thus, the trader can exploit the farmer's uncertainty and risk aversion and offer his certainty equivalent (i.e., the price that would make the farmer indifferent about going to the market or selling at farm gate, net of transportation costs). This model predicts that the trader will profit and that this profit will depend on the farmer's degree of risk aversion and on the uncertainty of market prices.

Both of these models rely on the assumption that there is limited competition between middlemen. Competition among traders would ensure that they could not make profits from the transactions with farmers. However, there are a number of reasons why, in theory, traders could exercise significant market power. Mérel et al. (2009) argue that high transportation costs can effectively increase middlemen's market power by limiting farmers' access to other potential buyers. Barrett (2008) posits that capital constraints can prevent entry into some segments of the food supply chain (for example, those that comprise wholesale purchases, interseasonal storage, or transportation across regions). Lopez & You (1993) argue that traders' market power can be sustained through oligopsony arrangements. Fafchamps & Hill (2008) present a model in which, despite free entry, traders can maintain market power. In their model, this entry increases uninformed farmers' search costs, as they have to compare prices among an increased number of potential buyers. Mitra et al. (2013) find that farmers may not be able to sell their crops directly in markets if wholesale buyers transact only with traders who can offer larger volumes and who are not willing to trade with smallholders.

Thus, traders' ability to maintain some degree of market power seems critical to models of asymmetric information and bilateral bargaining. Mitchell (2011) implicitly incorporates this idea into a two-period model, highlighting the role of market price information and competition among middlemen. In the first period, the farmer decides whether to sell his product to a trader or directly to a market. In the second period, he decides whether to stay with the same trader or to switch to a different trader, although this latter action may be costly. Mitchell's results suggest that a competitive environment with low switching costs encourages traders to make higher offers even in the absence of price information for farmers. As switching traders becomes more difficult, information acts as a substitute for competition to level farmers' farm-gate prices. However, as the market becomes more monopsonistic, information does not matter.

3.2. Agricultural Technology

There is a considerable agricultural productivity gap between developing countries and developed countries; heterogeneous technology adoption presents an important explanation for this gap. Foster & Rosenzweig (2010) highlight the importance of understanding adoption, arguing that "one mechanism by which poorer countries can catch up with richer countries is through technological diffusion." These diffusion processes have therefore been the subject of multiple analyses, highlighting the effects of extension services, network effects, and learning-by-doing (e.g., Foster & Rosenzweig 1995, 2010; Munshi 2004; Bandiera & Rasul 2006; Conley & Udry 2010; Genius et al. 2014). However, few researchers explicitly model how ICTs alter these effects.

Restuccia et al. (2008) present a two-sector general equilibrium model to investigate cross-country differences in productivity and agricultural technology adoption and argue that productivity gaps can be driven by barriers to the adoption of modern intermediate outputs (e.g., chemical fertilizers, pesticides, machinery, improved seeds) in developing countries. Jack (2011) identifies inefficiencies in seven different areas that may hamper technology adoption in developing countries: (*a*) externalities, (*b*) input and output markets, (*c*) land markets, (*d*) labor markets, (*e*) credit markets, (*f*) risk markets, and (*g*) information. She argues that one of ICTs' most important roles directly relates to the reduction of information deficiencies in developing countries.

Cole & Fernando (2012) find that traditional extension services face several constraints that limit their efficiency. First, because of poor infrastructure, visiting remote areas is hard and costly. Second, typical extension programs usually provide only one-time information to farmers, restricting the long-term impact of such programs. Finally, traditional extension is plagued by principal-agent and institutional problems, including a lack of accountability. Cole & Fernando argue that ICTs can overcome these constraints by reducing the cost of extension visits, enabling more frequent two-way communication between farmers and agents, and improving agents' accountability.

Aker (2011) argues that ICTs can also provide farmers with better access to private information from their own social networks. Technology adoption is related to observation of and learning from one's peers; thus, technology adoption may constitute an important channel for ICT use to impact agricultural development. By increasing communication linkages between individual farmers, extension agents, and research centers, ICTs can improve the flow of relevant information among all these agents.

4. EMPIRICAL EVIDENCE

4.1. Agricultural Prices

Empirical studies of the impact of ICTs, specifically mobile phones, in agricultural markets in developing countries have focused on ICTs' macro effects on agricultural prices, measuring price integration and price volatility in markets, and on ICTs' micro effects, measuring the price impact on farmers with access to mobile phones and on farmers with access to MIS delivered through ICTs. We review the evidence of these effects consecutively.

4.1.1. Impact of ICTs on price integration and price volatility. To examine the role of mobile phones in improving market efficiency, a number of authors look at ICTs' impact on price integration and price volatility; these authors mostly find a positive result. Jensen (2007) investigates sardine markets across the state of Kerala, India; these markets were characterized by considerable price heterogeneity and wastage. Following the introduction of mobile phones, fishermen had better information and were able to better arbitrage prices between markets, reducing price differences and virtually eliminating wastage. Abrahams (2007) reaches similar conclusions in a study of the same sector.

Aker (2010) analyzes the rollout of mobile phones across grain markets in Niger. She finds that the introduction of mobile phones led to a 10–16% reduction in the dispersion of grain prices across markets (i.e., the absolute value of price differentials between pairs of markets) and to a 10% reduction in the coefficient of intra-annual price variation within markets. Aker (2008) argues that the main reason for these reductions is traders' behavior: Traders with mobile phones are able to search for sales opportunities across more markets, reducing the variability in consumer prices.

In a complementary study, Aker & Fafchamps (2014) analyze whether mobile phone introduction also leads to changes in producer prices for millet and cowpeas in the same markets. Their results suggest that phones reduce producer price dispersion for cowpeas by 6%, with larger effects for market pairs that are farther away from each other and for those connected through unpaved roads. They also find reductions in the intra-annual coefficient of variation of farmers' prices. However, they do not find any significant impacts for millet, suggesting that information may have larger effects on perishable crops (cowpeas) than on less perishable ones (millet).

Analyzing the impact of an MIS on price variation, Goyal (2010) investigates the introduction of *e-choupals* (Internet kiosks) in Madhya Pradesh, India. The kiosks were implemented by a private soybean processor in an effort to cut out intermediaries in its supply chain. The *e-choupals* provide both the price that farmers would get for selling directly to the processor and the prevailing prices in local markets. The author finds that *e-choupals* led to a reduction in price dispersion.

4.1.2. Impact of ICTs on farm prices and income. A number of studies look at the impact of mobile phone access at the farm level. The available evidence of the impact of mobile phones on agricultural farm prices and income shows mixed results. Beuermann et al. (2012) show that villages with mobile phone coverage in rural areas of Peru experienced an 11% increase in total household expenditures between 2004 and 2009. Similarly, Labonne & Chase (2009) find that mobile phone ownership increases households' growth rate of per capita consumption by 11–17% among farmers in the Philippines. Although neither Beuermann et al. nor Labonne & Chase can directly test whether these increases are due to access to more profitable markets or due to better bargaining power against traders, they present some suggestive evidence regarding changes in farmers' likelihood of traveling to markets and in their relationships with traders.

Jensen (2007) finds that the introduction of mobile phones in Kerala led to a decrease in fish prices of approximately 4%, with enhanced arbitrage between markets. However, due to the reduction of wastage, fishermen's profits increased by an average of 8%. Muto & Yamano (2009) investigate the impact of the rapid mobile phone expansion that took place in Uganda between 2005 and 2009. They find that increases in phone coverage were associated with a higher probability of banana sales for farmers in remote areas and with increases in the sale prices of bananas in communities with a mobile network. However, they do not find any of these effects for maize, suggesting again that information may be more important for more perishable products than for less perishable ones.

However, a number of papers find little or no impact on marketing outcomes. In their analysis of mobile phone expansion in Niger, Aker & Fafchamps (2014) do not find increases in farm-gate prices for either cowpeas or millet. Futch & McIntosh (2009) investigate the introduction of village phones in Rwanda and find that the technology did increase the proportion of farmers arranging their own transport to markets. However, ultimately, the village phones do not appear to have increased the prices received by those farmers.

4.1.3. Impact of MIS delivered through ICTs on farm prices and income. Several authors look at the impact of MIS spread through ICTs and mobile phones. Although the results are again mixed, the majority of the studies find no impact; when an impact is found, it exists only for a subset of commodities, pointing to strong, heterogeneous impacts. In their impact evaluation of ESOKO (an ICT platform for agricultural information in Ghana), Nyarko et al. (2013) find that farmers with ESOKO access sold their yams at 11%-higher prices than did farmers without this service. Their evidence suggests that this effect is likely driven by farmers' improved bargaining power against traders. However, Nyarko et al. find no price increases for maize, cassava, or *gari* (a by-product of cassava), suggesting that information may have differential effects by crop type.

Nakasone (2013) implemented a randomized controlled trial among smallholders in the Central Highlands of Peru. In this trial, a group of farmers in treatment villages received price information for different crops through SMS in six alternative reachable wholesale markets. He finds large impacts on the average prices received by farmers (with price increases of 11–13%), driven mostly by increases in prices for perishable crops (lima beans and peas) rather than by increases in prices for nonperishable ones (different types of barley, corn, potatoes, and other Andean tubers). His analysis also suggests that, rather than driving farmers to sell directly to markets, information improves farmers' bargaining power against agricultural traders.

However, other studies do not find such effects. Fafchamps & Minten (2012) investigate the impact of Reuters Market Light (RML), a service that provides farmers with agricultural information through mobile phones in Maharashtra, India. They implemented an experimental evaluation in which a random sample of farmers received a free RML subscription for a year. Although the authors find that younger farmers received slightly higher prices for their crops, they do not find differences in average prices for farmers with RML subscriptions. The authors suggest that low levels of actual RML usage[5] and the fact that farmers sold mostly to a single local market may have contributed to this result.

[5]The authors report some causes for limited usage of RML: Some farmers thought that they would be charged if they used RML, subscribers did not know how to activate the service (they had to indicate the crops and markets they were interested in), there were phone number changes, and there were problems with Chinese phones that did not display messages in local languages.

Mitra et al. (2013) collected daily price data in West Bengal for the two most important types of potatoes in local markets and in the closest metropolitan market and tested whether different means of information provision generated different impacts among farmers. Out of 72 villages, in one-third of them, the authors posted potato prices for the two nearby local markets and for the closest metropolitan market on public boards. In another third, this same information was delivered through phone calls to randomly selected farmers in the village, whereas the remaining third was a control group. Mitra et al. do not find price increases among farmers who received information through any of these alternative means. This result may be attributable to characteristics specific to the area, as these authors find that large wholesale buyers were not willing to buy directly from smallholders and negotiated only with middlemen with whom they could trade larger volumes. Hence, even when farmers are more knowledgeable about prevailing market prices, information may not alter their options when these farmers negotiate with middlemen.

Camacho & Conover (2011) conducted a randomized controlled trial among famers in Colombia. A randomly assigned sample received market prices through SMS to their mobile phones. The authors find that, although treated farmers seemed to increase their knowledge about prevailing market conditions, this increasing knowledge did not translate into better sales prices, agricultural revenue, or household expenditures.

A number of authors further evaluate the effect on farm prices of MIS not implemented through mobile phones. Goyal (2010) finds that the introduction of *e-choupals* in India had a positive effect on soybean prices, with a 1–3% increase in markets located in districts where kiosks were introduced. This technology also yielded a 19% increase in soy production, leading to an overall increase of 33% in farmers' net profits, most of which seems to have come from a redistribution of surpluses away from traders. Other authors look at the effect of mass media on farm prices;[6] however, that literature is beyond the scope of this review.

4.2. Impact of ICTs on Agricultural Technology Adoption

Although a wide array of projects use ICTs in developing countries to improve the spread of information related to improved agricultural technologies and management practices, only a few evaluations of these projects have been conducted. In their investigation of RML in India (described in Section 4.1), Fafchamps & Minten (2012) examine the impact of RML's delivery of crop advisory tips (offered for one crop chosen by the farmer). The hypothesis was that this information would change farmers' cultivation practices or reduce harvest losses; however, the study finds no such effect.

Cole & Fernando (2012) conducted a randomized impact evaluation of the Avaaj Otalo (AO) program among cotton farmers in Gujarat, India. In this program, information was delivered through voice messages rather than through SMS. This system provided both push content (weekly information on weather and crop conditions) and pull content (a hotline for specific advice). Results show that households benefiting from AO shifted their pesticide use to less hazardous and more effective products; the results also suggest that beneficiaries were more likely to harvest cumin, a high-value cash crop.

[6]For example, Svenson & Yanagizawa (2009) study the impact of radio shows broadcasting market prices for different agricultural commodities. They find that farmers who received the price information achieved a 15%-higher farm-gate price for maize. The treatment also increased maize sales, thus implying an overall increase of 55% in farmers' crop revenues (Svenson & Yanagizawa 2009).

Fu & Akter (2012) investigate the impact of a program termed Knowledge Help Extension Technology Initiative (KHETI) in Madhya Pradesh, India. Although KHETI does not provide information directly to farmers, it operates through agricultural specialists who travel across villages with special mobile phones. These phones can record short dialogue strips (SDSs), short videos depicting a particular problem faced by farmers. The specialists send these SDSs to scientists, who determine solutions for each case presented; these solutions are then passed back to the farmers. Using difference-in-differences estimations, Fu & Akter find that those in the KHETI group[7] increased their awareness and knowledge of extension services compared with a control group. The authors also provide before-and-after comparisons for beneficiaries, indicating that farmers perceive KHETI as being more useful, faster, and of better quality than other services.

Finally, two studies look specifically at the impact of weather information spread through mobile phones (Camacho & Conover 2011, Fafchamps & Minten 2012). It is hypothesized that spatially disaggregated weather forecasts help farmers improve yields because they can take better anticipative action to deal with weather shocks; however, neither of these studies finds such an impact.

5. CONCLUSIONS AND IMPLICATIONS

Developing countries' access to mobile phones has increased considerably over the past decade. By 2012, there were an estimated 0.82 mobile phone subscriptions per capita in developing countries. However, access to other ICTs remains rather low, leaving considerable room for improvement. We also note a significant gap in access between urban and rural areas, consistent across all continents. Moreover, although there are an increasing number of initiatives using mobile phones for the delivery of extension messages, mobile phones' use for these purposes is still limited.

These changes in ICT access in rural areas have led to a rapidly increasing body of theoretical and empirical research work on ICTs' implications for agricultural development. Most evidence suggests that the spread of mobile phones leads to better market integration and to less price volatility. Access to mobile phones in rural areas seems to increase agricultural market performance, possibly through better arbitrage opportunities. Even when farmers have little access, mobile phones still impact the functioning of agricultural markets because of widespread use by traders. However, the impact of mobile phones on farm prices and farm incomes is mixed. Finally, assessments of MIS delivered by mobile phones show that, in general, there is no impact on farm prices or income. When a positive impact is found, it is limited mainly to perishable, high-value crops.

These varying results may be due to characteristics specific to the studies or due to the market structure in the particular study regions. If farmers do not have outside options for their sales, information will do little to improve their marketing outcomes. However, if there is scope for outside options and increased bargaining power, improved information may present potential gains. The available studies also seem to indicate that there can be considerable heterogeneous effects, depending on the perishability of the product, on farmers' initial information about prevailing market conditions, and on the relationships between producers and traders.

Extension systems by mobile phones and other ICTs have yet to be examined fully. Drawing firm conclusions is difficult because there are only a limited number of studies on extension effects

[7]All households in the KHETI group were previously part of an association of poor and marginalized farmers in Madhya Pradesh. Given that the treatment and control groups may have had different characteristics to begin with, these results should be interpreted with caution.

and because of the heterogeneity of extension projects: one-way versus two-way communication between farmers and agricultural specialists, SMS versus voice messaging, and oral description of problems versus pictures taken in the field. There remains a lack of evidence regarding which services work best, as most agricultural extension through ICTs is fairly recent. Although farmers' awareness of improved technologies and techniques may increase through these programs, the available evidence suggests that such increased awareness does not automatically translate into behavioral changes such as increased adoption of improved agronomic practices or modern inputs.

Our review suggests a number of areas for future research that are related mostly to further empirical work. First, the available literature shows heterogeneous impacts of MIS. For example, some of the results may be driven by significant price information asymmetry in areas where mobile phone penetration levels are low; in such a case, as penetration, and therefore access to price information, increases, the type of information may matter significantly more. Further research is called for in this area.

Second, there is a general lack of evidence regarding the impact of extension advice through ICTs. The financial sustainability of ICT-driven extension services and climate information must be further studied, especially in relation to the information's disaggregation levels. Although the information provided to farmers must be locally relevant and specific to the needs of the farmer, the generation of such local content can be very costly.

Third, information may lead to the adoption of agricultural techniques or to changes in cropping patterns among uninformed farmers; however, other constraints (such as a lack of irrigation or credit constraints) may prevent farmers from adopting new practices, even when they become aware of them (Mittal et al. 2010, Glendenning & Ficarelli 2012). Better understanding the relative benefits of improved information in the household economy is a major research challenge.

Fourth, how information is delivered also needs to be considered. On the one hand, SMS messages can be effective for simple price or weather information; however, data limitations (usually 160 characters) may render such messages ineffective in providing more complex advice about agricultural practices or new technologies. Farmers may also need a higher level of ability or literacy to process the content of these messages. On the other hand, although voice messages may be more suitable, they are more complicated and costlier to implement. Assessing the benefits and costs of these different delivery mechanisms would therefore be useful.

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