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Will Digital Technologies Transform Agriculture in Developing Countries?

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Abstract

Mobile phones and the internet have significantly affected practically all sectors of the economy, and agriculture is no exception. Building on a recent World Bank flagship report, this paper introduces a concise framework for describing the main benefits from new information and communications technologies. They promote greater inclusion in the broader economy, raise efficiency by complementing other production factors, and foster innovation by dramatically reducing transaction costs. The paper reviews the recent literature on corresponding technology impacts in the rural sector in developing countries. Digital technologies overcome information problems that hinder market access for many small-scale farmers, increase knowledge through new ways of providing extension services, and they provide novel ways for improving agricultural supply chain management. Although there are many promising examples of positive impacts on rural livelihoods—or "digital dividends"—often these have not scaled up to the extent expected. The main reason is that technology can only address some, but not all, of the barriers faced by farmers in the poorer countries.

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Will Digital Technologies Transform Agriculture in Developing Countries?

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1. Introduction

The internet, mobile phones, and related technologies that facilitate the collection, storage, analysis and sharing of data and information are changing many aspects of life among a large and growing share of the world's population. These digital technologies have been spreading rapidly. Even among the poorest 20 percent in developing countries, 70 percent have access to mobile phones (World Bank 2016). This is more than have access to improved sanitation or electricity in their homes. More than 40 percent of the global population has internet access and there are major initiatives underway to connect those still unconnected—the great majority of them in rural areas in developing countries.

Digital tools generate immediate private benefits as people can more easily communicate with friends and family and access new forms of leisure and new sources of information. These are highly valued benefits that explain the fast adoption of mobile phones even among those with few means. A larger question is whether new technologies also significantly promote economic development. There have been many claims of immediate and large effects, not least from politicians and technology boosters in industry. Solid empirical evidence based on careful identification of impacts is much harder to come by.

There are indeed a number of compelling examples across sectors of the economy where technology has improved economic prospects, helped support livelihoods and facilitated service delivery. In agriculture, Jensen's seminal study of Kerala fishermen provided a clean identification of significant impacts of mobile phones on earnings, price volatility and reducing waste (Jensen 2007). Aker's work on small-scale African farmers showed significant time and cost savings in using information and communication technology (ICT) for extension services (Aker 2011). At the other end of the productivity spectrum, modern large-scale agriculture is becoming unthinkable without such precision agriculture tools as GPS, satellite and drone monitoring, and increasingly detailed and instantly available weather and climate information (Oliver, Robertson, and Wong 2010).

At the same time, despite many individual success stories in many sectors of the economy, there has been surprisingly limited evidence of aggregate improvements in important development outcomes. Globally, productivity growth has slowed, inequality is a rising concern not just in rich but also in low and middle income countries, and technology has not led to the widespread improvements in governance that many had predicted, for example, as seen by the aftermath of the protest movements in the Middle East and North Africa known as the “Arab Spring.” Technology is obviously not the cause of these trends, but it is important to ask why they are happening despite its supposedly transformational role.

This is the core question asked in the 2016 edition of the World Bank’s World Development Report *Digital Dividends*. The report reviews the empirical evidence of the impact of digital technologies on economic growth, opportunity for individuals, and public service delivery. Using a simple framework discussed in the next section, it presents many examples of benefits accrued to firms, workers and governments. But it also identifies a number of risks: Firms in poorer countries adopt digital technologies much more slowly than expected. Automation, increasingly of mid-level white collar jobs, is contributing to a shift of income from labor to capital and a hollowing out of the labor market, even in many developing countries. And despite large investments, e-government initiatives too often fail to improve how public services are delivered. Drawing on the economic literature in several subfields, the report concludes that digital technology will contribute to development less than expected when important “analog complements” are absent. Firms and farms will not invest in productivity enhancing technology when they are sheltered from competition. Workers will not gain, if limited skills do not allow them to leverage technology rather than be replaced by it. And governments will not have the incentives to deploy technology to empower citizens and deliver better services when institutions are not accountable. In other words, *digital dividends*—faster growth, more jobs and better services—will fall short if digital investments are not accompanied by long overdue reforms in a country’s business regulations, skills development systems, and public sector governance.

Drawing on the lessons from the World Development Report 2016 (WDR), this paper provides a brief review of the impact of new digital technologies on development in the rural sector of developing countries. The following section introduces a simple framework of technology’s impacts. ICTs support development objectives principally by allowing more people and firms to participate in markets (inclusion), by making existing factors more productive (efficiency), and by supporting large economies of scale enabling new business models (innovation). The following sections apply this framework to the rural space, stressing the role of information, especially about markets (Section 3), of improved knowledge by making extension services more widely available (Section 4), and of closer links between buyers and sellers through innovative logistics chains (Section 5). Section 6 concludes.

2. Old economics explains the new economy

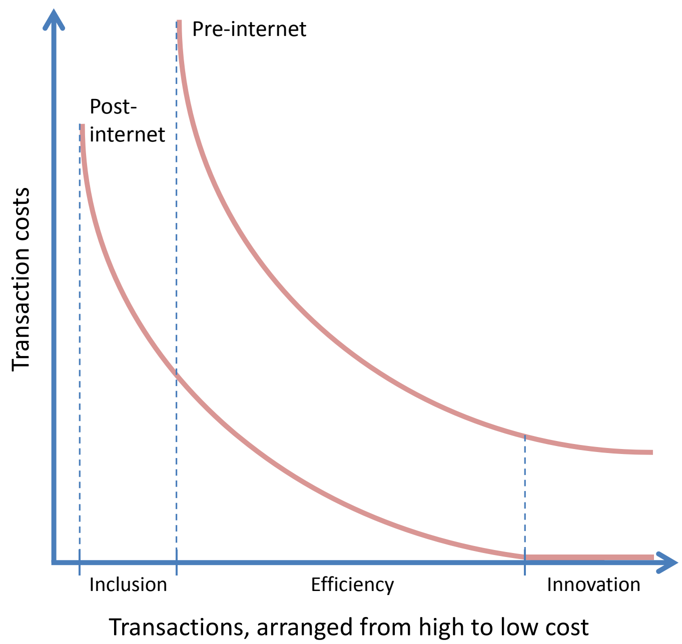
Given the significant impact of the internet on almost all parts of the economy and society, one might have expected the emergence of a new branch of economics providing the theoretical underpinnings of the digital revolution. There is indeed a considerable literature on the topic. In 1994, MacKie-Mason and Varian presented “Some Economics of the Internet,” introducing the technology and discussing economic implications of the network’s management. The short introduction of the economics of information technology by Varian, Farrell and Shapiro (2004) remains a useful overview. More recent papers look at specific aspects of the internet, such as the functioning of internet markets (Ellison and Ellison 2005, Levin 2011) or the internet as an increasingly important source for large data sets that are useful in economic inquiry (Varian 2014). Greenstein, Goldfarb and Tucker (2013) pull together a number of important papers on specific aspects of digital technologies. But none of these publications proposes a fundamentally new way of thinking about economic processes in the internet age, because “*there was never a new economics to go along with the new economy*” (Varian 2002).

Classic economic concepts thus explain the impact of the internet and related technologies quite well. Most fundamentally, these technologies reduce the money and time costs of accessing and exchanging information. They therefore reduce transaction costs, defined by Ronald Coase, in his 1937 paper on the nature of the firm, as the costs of using the market mechanism—though the same principles also apply to many non-market transactions and social interactions. In a standard definition they include the cost of searching and exchanging information, of bargaining and decision making, and of policing and enforcement. The internet has made many types of transactions much easier, quicker and cheaper—although there are exceptions such as complex contract negotiations.

Transaction costs are a very broad concept and some researchers have argued that they should be more narrowly defined and measured (Wang 2003). There are also subtle differences in the use of the term in the property rights literature that also has its roots in Coase’s work (Allen 1999).

But abstracting from these more narrow debates, the general concept of transaction costs is helpful in describing how new technologies impact economic development. A simple thought experiment will help. If we could measure the costs of all transactions in an economy, we could arrange them from highest to lowest as in Figure 1. New technology, especially the internet, facilitates information exchange and other forms of communication and thereby lowers the curve. In reality we do not know the shape of the curve and the drop in transaction costs will not be uniform as implied in the chart, leading to a reordering of transactions by cost. But most generally, we can expect three effects.

Figure 1: The effects of falling transaction costs



Source: World Bank (2016).

On the far left of the curve there were some transactions whose cost was so high that they simply did not take place. In the simplest case, two parties to a potential transaction simply did not know about each other—for example, a producer of a specialized product for which there might be high demand in a distant place. Or someone faced insurmountable barriers to participating in a market. Examples are persons with disabilities who are mobility-constrained or prevented from easily communicating with others; or women who cannot enter the labor market because child rearing or cultural norms prevent them from working outside the home. In other cases, the two parties may know about each other, but one party has more information than the other. For example, a lender will be unwilling to extend a loan to a small-scale farmer because there is no easy way to ascertain creditworthiness. Such information problems, in particular information asymmetries, have been widely studied, including by George Akerlof, Michael Spence, and Joseph Stiglitz who jointly received the 2001 Nobel Prize for work in this area. Today, technology helps the disabled use text, voice and video to communicate, people can more easily work from home—even for clients half-way around the world—and new data sources such as mobile phone records help extend credit even to those lacking access to formal banking services. In the "market for lemons" (Akerlof 1970), websites that document a vehicle's history now reduce the information gap between seller and buyer. More generally, from the perspective of the individuals now able to participate in all of these markets, the result is greater inclusion. From the perspective of a seller or service provider, this expands the market.

The middle part of Figure 1 is closest to the original Coasian concepts. It covers transactions that already took place, but that now have become cheaper, faster or more convenient thanks to new technologies. By automating or facilitating some processes, such as communicating with buyers or suppliers, it makes other factors more productive. Most importantly, easier coordination improves capital utilization as in the sharing or renting of tractors, and labor productivity, for example, through access to critical information via mobile phones or internet. Human capital augmenting technology has always been at the core of productivity improvements and therefore of increasing welfare, from the simplest Stone Age tools to the industrial revolution, and the digital revolution is just the latest stage in this process (e.g., Autor 2015). This increases efficiency in the economy.

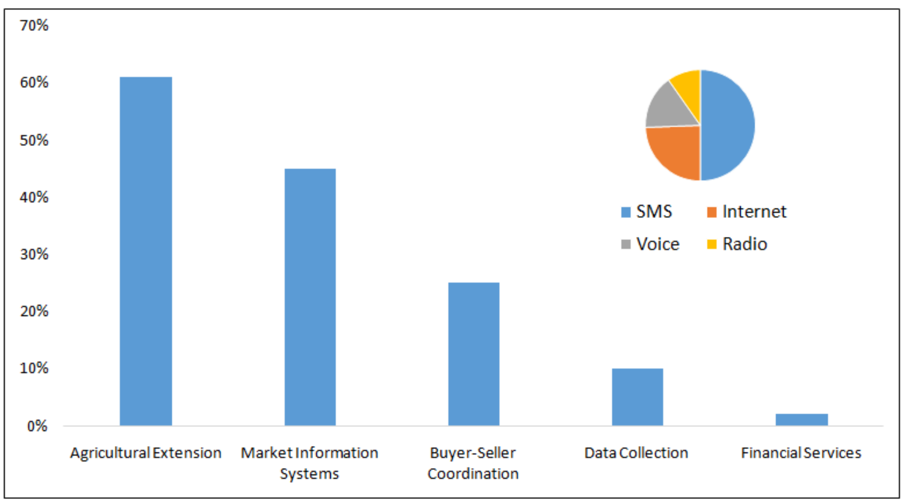
On the right of Figure 1, finally, transaction costs fall to such a level that they are essentially negligible at the margin. Processes can be fully automated on at least one side of the transaction as in e-commerce applications or in matchmaking in the on-demand economy for transport or hospitality services. If the service is to provide a digital product, (re)production costs are also essentially zero as in electronic news or music. The new companies and services in this area are most directly associated with the new economy, which is characterized by a high degree of innovation. Their cost structure of high initial investments to build an internet platform but very low costs of individual transactions gives rise to scale economies both on the supply side (average costs drop with the number of transactions) and on the demand side (average revenue or utility rises with the number of users or customers) (Varian, Farrell and Shapiro 2004). This market structure and the resulting network effects can lead to the emergence of monopolies, similar to markets for electricity and other utilities which tend to require some degree of regulation. Indeed, the internet is characterized by the emergence of dominant firms and intermediaries, although consumers have so far rarely been hurt, especially given that access to many of the new services is free and financed through advertising.

Many of the new innovative services operate on platforms or two-sided markets where an intermediary brings together buyers and sellers or users and providers. Again, two-sided markets existed before the internet and their market structure and implications for competition policies have been extensively studied (Rochet and Tirole 2003). Platform competition also illustrates that in many real-world examples, the three mechanisms illustrated in Figure 1 operate at the same time. So for a transport service in the sharing economy, for instance, the innovation is the automated platform making the match and providing useful information; for the drivers it is inclusion as they can access an income earning opportunity otherwise out of reach; and for the customers it is efficiency as the new service is usually cheaper and often more convenient.

Information and communication costs also play a large role in agricultural production in the developing world, where it sustains the majority of rural livelihoods. Ever since people have grown crops, raised livestock, and caught fish, they have sought information from one another—about the most effective planting strategy, sources for improved seeds, or the best price in a market. Over time, weather patterns and soil conditions change. Epidemics of pests and diseases come and go. Updated information and the ability to exchange knowledge allow farmers to cope with and benefit from these changes.

Mobile phones and the internet therefore have the potential to contribute to productivity improvements in the rural sector. Following the simple framework outlined above, technology can help in three main areas that are also the principal focus of interventions aimed at improving agriculture in developing countries. First, they overcome information problems, most importantly the ability to access market information, and reduce persistent information asymmetries caused by reliance on market intermediaries. This promotes the inclusion of rural and often marginalized producers in regional, national or even global markets. Second, to raise on-farm productivity, the demand for timely and precise information on input use has increased. . Better information delivered through extension services—about agricultural practices, new tools or new seeds—increases access to suitable technologies and makes other forms of capital more productive, thereby making production more efficient. This remains the most common component of World Bank agricultural development projects (Figure 2).[1] And third, agriculture can benefit from major innovations including logistics platforms that better link buyers and sellers along the agricultural production chain. Short messaging service (SMS) or "texting" is the most used technology in these projects, because even poor farmers now tend to have access to feature phones, but about a quarter of projects now employ internet tools. There has been a slow but steady growth in rigorous, quantitative evidence on the ways in which digital innovations help improve the lives of rural people (see summary Table 1 below), although much still remains to be done. The following sections briefly review this evidence.

Figure 2: Widespread digital technology tools (pie chart) and functions (bar chart) across agriculture projects



Source: Review of World Bank Agriculture Projects, 2015

[1] A survey of agriculture projects promoting the use of digital tools, recently funded by the World Bank, indicates that a majority of ICT and agriculture interventions are focused on providing agriculture extension services, market information systems and arranging logistics (World Bank 2011).

Table 1: Impact of digital technology interventions on agriculture outcomes

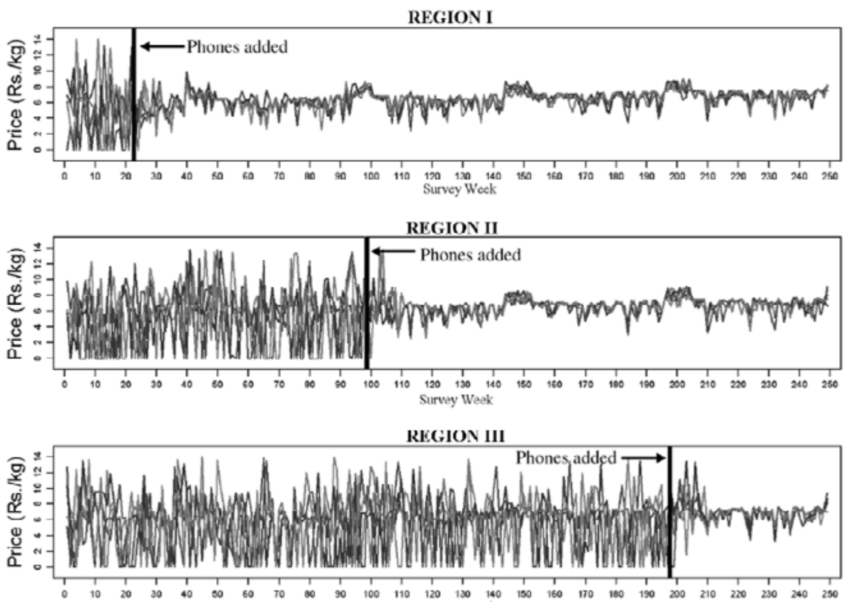
Main Finding	Location; Product; Technology; Study
Improve Market Transparency	
Greater arbitrage opportunities, reduction in spatial price dispersion, lower wastage, increase in both consumer and producer welfare	• Kerala, India; Fisheries; Mobile phone coverage; Jensen (2007) • Uganda; Range of Crops; Radio; Svensson and Yanagizawa (2008) • Niger; Grain; Mobile phone coverage; Aker (2010)
Increases in farm-gate prices from improvements in bargaining power with middlemen, greater market participation in remote areas through more efficient coordination	• Uganda; Maize and Banana; Mobile phone coverage; Muto and Yamano (2009) • Madhya Pradesh, India; Soybeans; Internet Kiosks; Goyal (2010) • Gujarat, India; Range of Crops; SMS; Mitchell (2014)
Context specific factors and various marketing and institutional constraints can blunt benefits	• Rwanda; Range of Crops; Mobile phone adoption; Futch and Mcintosh (2009) • India; Range of Crops; SMS; Fafchamps and Minten (2012) • West Bengal, India; Potato; SMS; Mitra et al (2015) • Ethiopia; Cereals; Mobile phone coverage; Tadesse and Bahiigwa (2015)
Enhance Farm Productivity	
Facilitates adoption of improved inputs by providing extension advice and weather forecasts at a lower cost and encouraging agricultural investment decisions	• Ethiopia; Range of Crops; Videos; Gandhi et al (2009) • Gujarat, India; Cotton; Hotline voice service; Cole and Fernando (2012) • Ghana; Range of Crops; Mobile phone coverage; Al-Hassan, Egyir, and Abakah (2013)
Improvements in rural households' food security, income, value of assets through enhanced management practices	• Philippines; Ranges of Crops; Mobile phone adoption; Labonne and Chase (2009) • Sri Lanka; Fruit and Vegetables; SMS; Lokanathan and de Silva (2010) • Peru; Range of Crops; Mobile phone coverage; Beuermann et al (2012)
Success of digital technology interventions depend on broader institutional support such as political empowerment, human capital, and income inequality.	• Cross country data; Range of Crops; ICT; Lio and Liu (2006) • Morocco; Range of Crops; Mobile phone adoption; Ilahiane and Sherry (2012) • Kenya; SMS; Ogutu et al (2014)
Enable Efficient Logistics	
Optimize supply chain management, enhance coordination of transportation, delivery of products, and improving capacity utilization	• South Africa; web based systems; Van Rensburg (2004) • Zambia; SMS based service; Dixie and Jayaraman (2011)
Ensures food safety in global agriculture product chains, tracing from point of origin to consumers	• Namibia; Beef; RFID; Cabrera et al. (2010) • Colombia; Coffee; Karippacheril et al. (2011) • Mali; Mangoes mobile phone platforms; (Annerose 2010)
Facilitates secure payments, allows fast and safe transfer of funds to pay for products and inputs, agricultural subsidies, or remittances	• Nigeria; e-wallet; Grossman and Tarazi (2014) • Kenya; Mobile money; Jack and Suri (2014); Mbiti and Weil (2015)

3. Facilitating market transparency

Agricultural product markets in many developing countries are often poorly integrated (Bardhan 1989, Banerjee and Munshi 2004). High search costs have tended to lower competition and create an inefficient allocation of goods across markets. Moreover, high and volatile food prices lead to severe negative consequences for the welfare of the poor. Agricultural supply chains are often dominated by various intermediaries with substantial market power. While intermediaries deliver critical services to rural producers, they are also often exploitative and there can be large efficiency gains from their removal (Besley and Burgess 2000). One source of market power lies in the fact that middlemen are better informed about market conditions, especially the prices further down the supply chain. This raises the possibility that better access to market information can increase the prices that farmers receive from middlemen, thereby increasing their income and helping them to make better production decisions. Improving the efficiency of agricultural markets is therefore a priority.

When the internet took off in the mid-1990s, it was often claimed that it would improve price transparency, cut out middlemen, and make markets more efficient. Indeed, rapid adoption of digital technologies has dramatically reduced the search costs incurred by farmers and traders, and hence overcome an important constraint in the context of limited infrastructure. In Robert Jensen's 'classic' study of Kerala sardine fishermen and wholesalers, new mobile phone service dramatically reduced price dispersion and waste, increasing welfare for producers and consumers (Figure 3). While the perishability of fish, in this case, led to unique arbitrage opportunities, positive effects have also been shown for other commodities such as cereals and cash crops using a variety of communication platforms such as Esoko in Ghana (Niyarko et al 2013), e-choupals in India (Goyal 2010), telecenters in Peru (Beuermann et al 2012), as well as in studies on Niger grain traders (Aker 2010) and Philippine farmers (Labonne and Chase 2009).

Figure 3: Introduction of mobile phone service reduces price dispersion
Sardine prices in three coastal markets in Kerala, India



Source: Jensen (2007)

Digital technologies have had important impacts in linking farmers to markets and key stages of the value chain. A recent study of farmers conducted in Bangladesh, China, India, and Vietnam found that 80 percent of farmers in these countries owned a mobile phone and used them to connect with agents and traders to estimate market demand and the selling price (Reardon et al 2012). More than 50 percent of these farmers would make arrangements for sale over the phone. The growing sophistication and knowledge of value chains also means that farmers can work directly with larger intermediaries, capturing more of the product's value. Farmers are able to expand their networks and establish contacts directly with other buyers. The prevailing market price signals the aggregated demand and value on any given day and fluctuates over time.

Before the expansion of mobile networks, agricultural producers were often unaware of these prices and had to rely on information from traders and agents to determine whether, when, where, or for how much to sell their crops. Delays in obtaining this data or misinterpretation of second-hand pricing information has serious consequences for agricultural producers, who may end up underselling their products, delivering too little or too much of the product, or having their products wither away. Further, reliance on traders or agents creates rent seeking opportunities, adding to the agricultural workers' cost of business (Mitchell 2014). This "information asymmetry" often results in price dispersion—drastically different prices for the same products in markets only short distances apart—and thus lost income for some farmers and higher prices for consumers (Tadesse and Bahiigwa 2015).

A number of recent empirical papers have investigated the effects of better market information on producer prices, although results have been mixed. Svensson and Yanagizawa (2009) found that having access to regular market information via radio was associated with 15 percent higher farm gate prices in Uganda. The results from an experiment in Rwanda, on the other hand, found no effect of having a mobile phone on prices received by farmers (Futch and McIntosh, 2009). Fafchamps and Minten (2012) look at the effect of SMS-based agricultural information on producer prices in India and find that access to information did not significantly increase the prices they received, whereas Muto and Yamano (2009) found that in Uganda mobile phone coverage had a positive effect on farm-gate prices for bananas. They did not find a significant impact on prices for maize, however. Aker and Fafchamps (2015) also find that the effect of mobile phones varies by crop in Niger. They report that there is no significant effect on average producer prices, however there is a reduction in the variability of prices for cowpea but not for millet.

Using examples from Tanzania, Molony (2008) argues that the ability of producers to use price information may be limited by the fact that they are tied in to relationships with particular middlemen and are dependent on them for credit. Since they do not have an option to trade with someone else if they are unsatisfied with the price they receive, being informed about the market price does not help them. These results suggest that the benefits of information to farmers vary depending on what options are available to them. While the rapid increase in mobile phone coverage and ownership in developing countries is making it easier to provide farmers with accurate, (near) real-time information on prices to help them make optimal marketing decisions, it is important to carefully analyze the differing marketing institutions, the nature of interlinked transactions between buyers and sellers, as well as the vast heterogeneity across crops, for optimal design of such innovative programs.

4. Enhancing on-farm productivity

Agricultural productivity varies dramatically around the world. While credit constraints, missing insurance markets, and poor infrastructure account for some of this disparity, suboptimal agricultural practices and poor management are also to blame. New production technologies such as improved seed varieties, nutrient management, and pest control methods, are not necessarily reaching farmers. The low rates of adoption in developing countries have been well-documented, and there is widespread theoretical and empirical literature identifying the determinants of agricultural technology adoption in different contexts (Foster and Rosenzweig 1995; Duflo, Kremer and Robinson 2008; Conley and Udry 2010; Suri 2011).

Farmers face a range of potential production technologies and practices to choose from, each of which may have different risk profiles and different suitability for a farmer's own plots. To make those decisions, farmers must have information that the technology exists; they must believe that the technology is beneficial; and they must know how to use it effectively (Bardhan and Mookherjee 2011). Information provision encourages poor farmers to make profitable decisions to invest in new technologies. While agricultural extension is the most common way to communicate information to farmers, business-as-usual extension systems have had low usage from farmers and often promoted technologies that are either unprofitable, or whose costs and benefits are already well known to farmers. Agricultural extension (broadly the "delivery of information inputs to farmers") has traditionally been the primary means of reducing the information asymmetries related to technology adoption in both developed and developing countries (Andersen and Feder 2007). The general extension approach uses specialists to provide a range of services to farmers, from technology transfers to advisory services and human resource development.[2] Public extension agents have tried to overcome some of these information barriers on new agricultural practices and technologies, but such programs have

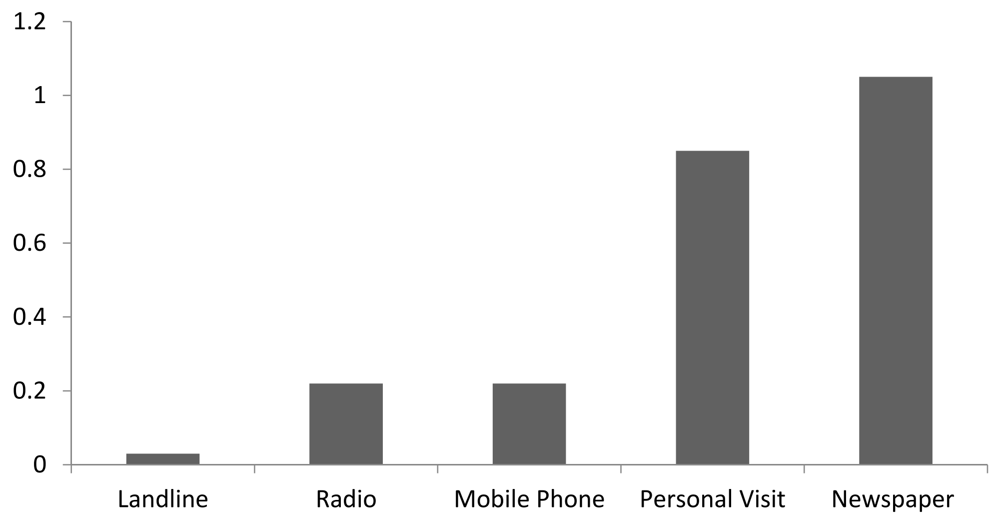
[2] In some cases extension approaches have also sought to connect researchers directly to the farmer in order to ensure that new technologies are better targeted to the specific conditions of agricultural communities. Agricultural extension models can take several forms. The most common approaches are Training and Visit (T&V), Farmer Field Schools (FFS) and fee-for-service. In the T&V approach, specialists and field staff provide technical information and village visits to selected communities. FFS also contacts farmers, relying on participatory training methods that build farmer capacities. Fee-for-service extension comprises both public and private initiatives with some public funding. In these programs, farmer groups contract extension agents with specific information and service requests.

typically been burdened by limited scale, sustainability, and impact (Rivera, Qamar and Crowder 2001).

Farmers tend to be more receptive to information that is easier to access than traditional extension services, and more tailored to their specific context. This highlights the need to explore information provision systems which, in the context of the adoption of novel technology, tailor lessons to farmers' specific contexts and more efficiently target farmers through information networks (Davis and Sulaiman 2014). Digital tools have thus enabled the revival of agricultural extension and advisory services to some extent. For instance, in cooperation with agricultural research and extension services, organizations such as Digital Green, the Grameen Foundation, Reuters Market Light, and Technoserve are able to deliver timely, relevant, and actionable information and advice to farmers in South Asia, Latin America, and Sub-Saharan Africa at a dramatically lower cost than traditional services (Nakasone, Torero and Minten 2014). Rather than always traveling to visit a farmer, extension agents use a combination of voice, text, videos, and internet to reduce transaction costs and increase the frequency of interaction with farmers. Similarly, governments, in partnership with mobile operators use phones to coordinate distribution of improved seeds and subsidized fertilizers in remote areas through e-vouchers, as in Nigeria's large-scale e-wallet initiative. Technology firms such as Climate Corp, based in Silicon Valley, are pioneering the provision of agrometeorological services for early warning of weather and climate risks. A number of innovations aim for real-time and accurate weather monitoring using remote sensing and GIS-enabled technologies for climate-resilient agriculture.

Electronic extension systems have typically tended to include a wide range of tools, software, platforms and devices with diverse sources of information. The simplest forms of e-extension are call lines/hotlines and radio/television programs, often with a questions and answers approach. Where modern digital technologies are not yet widespread these simpler tools remain effective, even though they allow for limited customization or interactivity. For example, while also experimenting with mobile phone based systems, a principal outreach strategy of Ethiopia's Agricultural Transformation Agency that now reaches 13 million smallholders relies on radio communication (ATA 2015). At the other end of the scale are highly advanced extension systems combining mobile tools linked to online platforms that are operated via smartphones or tablets. The e-extension system can be in the form of an online repository or information bank, with specific information on best practices for different crops suited to varying agro-climatic conditions, database of input retailers and prices. Similarly, e-extension can be in the form of participatory training videos disseminated via farmer groups and cooperatives for sending real time updates and pictures of damaged crops, for instance, to identify the cause and advice on treatment. In rural areas, the added value of e-extension is often, that with the help of communication tools, such as simple mobile phones, the extension officers can reach out to many more farmers than solely through field visits, especially in situations where the extension officer-to-farmer ratio is approximately 1:1000, a case common in many Sub-Saharan African countries, including Zambia and Uganda. Aker (2011) estimated that instead of traveling to visit a farmer, extension agents may use mobile phones for a comparative cost of one-fourth of the price of a visit (Figure 4).

Figure 4: Marginal (per search) cost of obtaining agriculture information in 2005 USD$



Source: Aker (2011)

In addition to making extension services more efficient, the improved outreach leveraged by such technologies contributes to inclusion and equity among the farmers. Although e-extension cannot entirely replace field advisory visits, it can still have a positive impact on farming and growth. Cole and Fernando (2012) show that in rural India, information provided via mobile phones to farmers increased their knowledge of available options for inputs such as seeds and fertilizers as well as choices of different crops leading to changes in their investment decisions and eventually to planting more profitable crops. The study demonstrated that the low-cost (0.60 USD per month) information was able to change the behavior of the farmers. Similarly, the Digital Green project, which started in India and has spread to other countries including Ethiopia, used a participatory process to let farmers get access to agricultural advice by connecting farmers with experts through a local social network. By minimizing the distance between instructors and learners, the initiative increases the adoption of certain agricultural practices seven-fold over classical extension approaches (Gandhi et al 2009). In the same way, a Chilean farming cooperative (Coopeumo) uses text messages to help small-scale farmers increase productivity, especially by providing targeted planting advice and weather updates that are particularly useful to farmers at critical points such as sowing and harvest (World Bank 2011).

Preventing losses through early warning systems have also been of growing interest, including climate models that raise public awareness of drought warnings, pest outbreaks, forest fire detection, and flood alerts, and thus give stakeholders enough time to react to emerging threats. Disease and meteorological information are required by farmers on a frequent basis. Without such information, farmers are unable to use timely measures to stem losses from climate shocks. Digital tools have been serving as the backbone for early warning systems to mitigate these risks and safeguard incomes.[3] Early warning systems typically use data from multiple sources, ranging from satellite images to classic surveys. For example, desert locust outbreak systems determine rainfall and vegetation cover from satellite images, after which the results are used to send survey teams to areas where the probability of a desert locust outbreak is most likely (Ceccato et al., 2014). A range of climatic parameters can be obtained from satellite imagery, and although the accuracy of satellite data is not always at the level of measurement stations, they provide almost real-time data on rainfall, temperature, evaporation, vegetation and land cover that are especially efficient in remote areas where other measurement infrastructure is lacking.

In addition to the monitoring systems that are based on collecting environmental sensor data, such as temperature and rainfall, we may, in the future, also see warning systems that are based

[3] For example, a publicly funded pilot project in Turkey provides locally relevant information to farmers in Kastamonu province, where producers maintain orchards susceptible to frost and pests (Donovan 2011). Initially, nationally aggregated weather data collected in urban areas was used but proved to be inaccurate and of limited use to farmers in the provinces, because of differing microclimates from farm to farm and differences in temperature, humidity, precipitation, and soil fertility. Five additional meteorological stations and 14 reference farms were then established to collect data on these variables, enabling accurate pest monitoring.

on social media or crowd sourcing. For example, it has been shown that in Indonesia, food price related tweets correlated with real events, and that the number of tweets on food prices correlated with food price inflation (Global Pulse 2014). Twitter, blogs and similar social networks may also provide early signs of emerging disasters. Extracting these early signs requires processing of huge amounts of data, a process where analytic tools developed for Big Data analysis will be useful. The potential of Big Data in agricultural research is in combining large amounts of data collected from various sources for making predictions over time, e.g., pest outbreaks, livestock behavior, or soils and weather.

Sophisticated precision farming systems are more commonly applied at technologically advanced farms and plantations, with the underlying logic to combine various remote sensing data and satellite imagery for a given farm parcel to provide precise information for growth (e.g., sensors for soil conditions, ground water level, and rain water precipitation detectors combined with irrigation optimization systems). As this can be done remotely, it saves significant time and labor when compared to manual sampling, and the use of calibrated technology makes the system less prone to error when assessing appropriate growth conditions (Hamrita and Hoffacker 2005). The benefit of the system is the resource optimization that can be done with the help of the information acquired. For example, the system can detect where there are nutrient deficiencies in the soil and thus additional fertilizers can be distributed to the areas where there is the most acute need for fertilizers instead of fertilizing the entire farm land as has traditionally been done. Irrigation or pesticide needs can similarly be detected and precisely applied. Digital tools can be applied to irrigation systems such as pumps that can be automated and controlled via mobile phones, such as the Nano Ganesh system in Pune, India where the farmers are able to save water, energy, and time by remotely controlling their irrigation pumps (Tulsian and Saini 2014). Precision farming requires investments in these systems, but once the systems are installed, it contributes directly to time, resource and cost-efficiency and thus to growth by releasing resources. Precision farming systems have also been shown to support environmental sustainability as the natural resources are being continuously monitored, and actions are taken accordingly, before nutrition depletion or drought takes place.

Although the demand for accurate production advice and early warning systems is high, there are significant transaction costs associated with providing these services such as the cost of developing and maintaining content as well as delivering this content on a timely basis at a large scale. These transaction costs are especially high in regions where agricultural productivity is low because low productivity is more likely to be associated with low overall economic development. In less developed regions with small-scale farm structures, poor public infrastructure, and insufficient human capital investments, there are higher transaction costs of providing relevant advice and services. As a result, low supply of agricultural advice and warning leads to a vicious cycle of inefficient production. In a more general framework, Lio and Liu (2006) investigate the impacts of information and communication technology on agricultural productivity using panel data for 81 countries during the period 1995-2000. They show gains in using low cost tools for improving the efficiency of delivering agricultural production advice, but caution that the returns from ICT in agricultural production of the richer countries are about two times higher than those of the poorer countries.

5. Enabling efficient logistics

Digital technologies also improve agricultural supply chain management. With globalized food systems, ensuring food safety has become more complex. These trends have catalyzed innovations to trace the food supply from producer to the consumer, important for developing countries that want to reach new export markets. Smallholder farms turn to cooperatives and aggregators who use digital tools to improve collection, transportation, and quality control. By opening up new specialized market opportunities, the internet improved consumer protection and farmers' livelihoods. Cunden and van Heck (2004) have argued that digital technologies have not only extended traditional market mechanisms into the electronic realm, but have also done so in areas where there are limited physical markets for buyers and sellers to gather in one place to begin with. Similarly, Site and Salucci (2006) argue that such technologies are especially useful in deep rural areas because of poor public infrastructure to facilitate rural farmers' access to local and global markets.

Transporting produce often requires coordination between producers, truckers, and, at times, warehouse owners and aggregate traders. Many producers, especially in remote and rural areas, must carry their produce themselves, often by foot, to the nearest collection point. Coordinating transportation is also important for larger traders who aggregate produce for sale in urban areas or for export. Studies show an increasing reliance on mobile phones to coordinate and relay information on transport and logistics (van Rensburg, 2004). The Zambia National Farmers Union operates an SMS based service that provides information on commodity prices and transport systems and allows registered transporters to publicize their arrival and delivery times of loads and cargo. First, producers can publicize the size of their load and where it is located for pickup and transportation from village to market, second, on the way back from the market, transporters can publicize an empty truck that could potentially be used to haul products back from the market to the village, and third, a directory of transporters makes this search process for producers more efficient. Similar services are used in Morocco, where through the use of voice and SMS, farmers coordinate with local truckers to improve product transportation and reduce post-harvest losses. Some farmers have also developed a two-way trade, bringing products back from the market to sell in their own rural communities (Dixie and Jayaraman 2011). Another example is M-Farm Ltd, an agribusiness company established by a group of women developers in Kenya. Besides the staple text-based service for obtaining price information, M-Farm enables suppliers to publicize information on special offers to farmers. This format follows a global trend in deal-of-the-day websites that feature discounted offers at local retailers, such as the Groupon service in the United States.

The growing globalized and interdependent nature of food production and distribution, combined with raised awareness of food-borne diseases, has shed light on the need to ensure food safety in the global food supply chain. These trends have catalyzed effective technological innovation to trace products from farm gate to market (Karippacheril, Rios, and Srivastava 2011). Traceability is becoming increasingly relevant to developing countries that want to reach or expand into new export markets. Smallholder farms, which often lack resources to keep up with the strict and changing food safety standards on their own, are now increasingly turning to cooperatives and aggregators who are leveraging ICTs to improve traceability. Radio frequency identification (RFID) chips are emerging as a promising solution for traceability. Placed on a crate of apples or in the ear of a cow, the chip can collect data such as motion, temperature, spoilage, density, light, and other environmental variables through an interface with wireless sensor networks. Traceability systems for bulk products have been implemented in developing countries, even among small-scale farmers. Representing more than 500,000 smallholders, the National Coffee Growers association in Colombia has leveraged RFID technology to improve traceability and recordkeeping on coffee quality standards. At a cost of $0.25 a tag, encased wear-resistant tags with unique farm identification numbers are distributed to farmers. These tags are read at each step to market, thus helping to maintain the stringent standards required for high-value specialty coffee.

RFID chips are also commonly used to trace animal movements, enabling the monitoring of animals from birth to the supermarket shelf. The Namibian Livestock Identification and Traceability System (NamLITS), implemented in 2005, focuses on nurturing livestock production for export markets. More than 85 percent of agricultural land in Namibia is used to raise livestock, and beef production constitutes 87 percent of agricultural revenue (Cabrera et al. 2010). The objective of NamLITS is to implement a traceability system to help in the control, risk management, and eradication of bovine diseases such as foot-and-mouth disease. The use of RFIDs to replace traditional paper-based recording, has increased the accuracy of the data and the speed with which it is disseminated. It has also contributed to a more vigorous market: the Namibian livestock market increased by approximately $83 million in 2010 (World Bank 2012). Similar approaches have been taken in other countries and other agricultural sectors.[4]

Meanwhile, financial innovations such as M-Pesa,[5] have had a significant impact on the ability of households to spread risk, and have been instrumental in allowing the transfer of purchasing power through a simple SMS-based technology. This has dramatically reduced the cost of sending money across large distances (Mbiti and Weil 2015). Families and other social networks in Kenya, for instance, are dispersed over large distances, due to internal migration, motivated by employment and other opportunities. Lowering transaction costs has important impacts on the size and frequency of domestic remittances and hence the ability to smooth risk. The predominant use of mobile money has been, and continues to be, person to person remittances.

[4] For example, Mali is a landlocked country with 80 percent of employment in subsistence agriculture and fishing. In the 1990s the government identified mangoes as having potential for diversifying the country's exports. It faced a number of challenges including meeting increasingly stringent criteria regarding the origin of products, the way they are grown, the fertilizers and pesticides used, and packaging. With the support of donors and NGOs, Fruit et Legumes du Mali (Fruilema), an association representing 790 small producers and five exporters, launched a web and mobile enabled platform through which buyers can track and monitor their mangoes (Annerose 2010). The consumer can type the number shown on a tag attached to the fruit into a website to get the exact details of where the mango came from, its producer, and the methods used to cultivate the mango. To leverage the mobile phone platform, Fruilema partnered with a Senegalese mobile operator, Manobi, to pay farmers an additional 9 cents a pound when they entered data on their produce on the Manobi website.

[5] M-Pesa (M for mobile, pesa is Swahili for money) is a mobile phone-based money transfer, financing and microfinancing service, launched in 2007 by Safaricom and Vodacom, in Kenya and Tanzania, and has since spread to many parts of the world. M-Pesa allows users to deposit, withdraw, transfer money and pay for goods and services easily with a mobile device.

Before the technology was available, most households delivered remittances by hand or informally through friends or bus drivers. This process was expensive, fraught with delays, and involved substantial losses due to theft. Now, all households need to do is send an SMS. Not only are the actual monetary costs of the transfers lower, but the safety and certainty of the process has meant substantial reductions in the cost of sending and receiving money. Four years after its launch, M-Pesa had been adopted by nearly 70 percent of Kenya's adult population and three-quarters of Kenyan households have at least one user. The fast adoption of M-PESA would not have been possible without the creation of a dense network of agents, small business outlets that convert cash to e-money and vice versa for customers; as well as the rapid expansion of mobile phone networks in Kenya (Jack and Suri 2014).

Effective logistics is critical for producers, retailers, as well as consumers for collection, aggregation, and delivery. Various field studies show that in many places digital technologies are quietly transforming how rural logistics function (World Bank 2011). The resulting improvement in logistics can be seen through lower transaction costs, improved profits, and less wastage. By giving people the ability to replace distance with "space-shrinking technology," digital tools enable market agents to better coordinate product supply and demand, strengthen existing trade networks, facilitate the assembly of products to reach a critical mass, and enable products to be delivered cost-effectively to new markets. Despite these positive impacts, complementary factors such as limited access to transportation infrastructure and insufficient financial services can still limit the gains of supply-chain efficiency.

6. Conclusion

As mobile phones and, to a lesser degree, the internet have reached rural areas in developing countries, a number of studies have shown encouraging impacts on overall returns received by rural producers. But there is also evidence that these innovations often fail to scale-up and achieve wider acceptance. Access to information and the ability to communicate are only two of many constraints farmers face. Others include market fragmentation (even though market consolidation will, over time, enhance growth prospects). Another reason could be the lack of financially sustainable business models that will attract private sector investments in providing innovative solutions for small scale agriculture. There is clearly high potential for the internet and related technologies to improve rural economies, but several lessons need to be kept in mind.

First, while agriculture continues to become more knowledge intensive and high tech, the demand for more precise and timely information rises rapidly. Some of the world's newest industries have started to put money and talent into farming—the world's oldest industry. Digital soil maps, remote sensing, and GPS guidance are critical tools for modern farmers. Big data for precision agriculture increases yields and efficiency. These high tech tools mostly benefit big farms that can make large investments in technology. Smaller farms will often not have the capital to keep up. This may change as information access and delivery continue to become cheaper. But even in the short term there are innovative ways in which smallholder farmers with limited human and financial capital investments use digital technologies such as basic mobile phones and increasingly the internet to maximize returns.

For this to have a widespread impact in rural areas of developing countries requires the closing of the remaining digital divide. While mobile phones have spread quickly even in low-income countries and among poorer population groups, access is by no means universal. And internet access remains very low in many countries. For example, the digital divide is large between and within 12 countries in Sub-Saharan Africa for which reliable data are available (Table 2 and Table 3). Mobile phone access is as high as 84 percent in South Africa, and as low as 18 percent in Ethiopia. Internet access is 34 and 3 percent, respectively, in the same two countries. Access is significantly lower in rural versus urban areas. Residents of rural areas in Ethiopia are only about one-fifth as likely to have access to a mobile phone as urban residents. On average, these disparities are as high as those between the bottom 40 percent and the upper 60 percent of the income distribution, and much greater than those between women and men, or between the old and the young.

Table 2: Individuals with mobile phone access, 2014

	All (percent)	Ratio rural / urban	Ratio women / men	Ratio age 45+ / 15-24	Ratio bottom40 / upper60
South Africa	84.2	0.94	0.96	1.04	0.89
Botswana	80.0	0.80	1.09	0.86	0.76
Kenya	74.0	1.01	0.81	1.09	0.73
Nigeria	66.4	0.86	0.72	0.87	0.74
Ghana	59.5	0.61	0.95	1.09	0.60
Namibia	56.1	0.60	1.04	0.85	0.57
Uganda	46.7	0.78	0.61	1.40	0.65
Cameroon	44.5	0.31	1.02	0.92	0.53
Mozambique	42.5	0.44	0.99	0.77	0.49
Tanzania	35.8	0.46	0.74	1.31	0.49
Rwanda	24.4	0.38	0.77	0.52	0.36
Ethiopia	18.3	0.22	0.42	0.79	0.27

Source: Gallup World Poll (various years). See World Bank (2016). Ratios refer to percentages, e.g., percent rural / percent urban.

Table 3: Individuals with internet access, 2014

	All (percent)	Ratio rural / urban	Ratio women / men	Ratio age 45+ / 15-24	Ratio bottom40 / upper60
South Africa	34.1	0.52	0.70	0.32	0.74
Botswana	29.0	0.55	0.81	0.23	0.51
Kenya	26.3	1.02	0.57	0.54	0.46
Nigeria	18.4	0.69	0.59	0.23	0.40
Namibia	16.2	0.15	0.76	0.37	0.32
Cameroon	14.1	0.11	1.09	0.48	0.48
Ghana	12.7	0.61	0.48	0.44	0.29
Mozambique	11.1	0.13	0.74	0.27	0.24
Uganda	7.9	0.38	0.26	1.92	0.28
Rwanda	6.0	0.24	0.76	0.58	0.15
Tanzania	3.5	0.20	1.04	0.60	0.22
Ethiopia	2.7	0.14	0.28	0.54	0.23

Source: Research ICT Africa surveys (various years). See World Bank (2016). Ratios refer to percentages, e.g., percent rural / percent urban.

Second, studies reviewed in this paper suggest that basic price and market information systems can improve efficiency and welfare. The evidence, though strong, is still limited to certain countries and in certain contexts. A number of recent studies have cast doubt on the overall novelty of information provided to the farmer with modern tools and the degree of competition in many markets. One explanation of weak effects is low take-up of fee-based price information services (Futch and Mcintosh 2009, Mitra et al 2015). But even when farmers are seemingly better informed, they may not necessarily be able to act on that information because of inaccessibility of alternative markets and the complex interlinked relationships between buyers and sellers in poor developing economies. Rather than assuming that an ICT approach will always be cost-effective and yield a better outcome, a more nuanced understanding of the underlying institutional environment and constraints is warranted.

An important insight, building on the work of Paul Romer, David Autor and others (see World Bank 2016, Ch.5), is that usually only some part of a task or service can be automated using technology while the remaining part requires non-routine skills such as discretion or complex problem solving that cannot be done by machines. A better understanding of the interplay of what is automatable and what is not could help better explain why some technologies (such as mobile money) take off, while others seem to underperform expectations. Such insights could also help design better interventions that leverage technology for rural development.

Third, technology-enabled interventions are no panacea in themselves, and need to be backed by complementary investments in physical infrastructure, electricity, literacy, and so on (Toyama 2015). The versatility and near-constant innovation that characterize digital technologies can sometimes be a distraction that can cause interventions to focus more on the technology than on the demands and priorities of the intended beneficiaries and the tradeoffs imposed by resource-constrained environments.

Finally, ICT policies and the broader regulatory environment in a country have to be discussed jointly. Whereas the expansion of mobile phone access has been rapid and commercially self-sustaining even among many of the poor, the same is not true of the internet. In the long run, the internet can have an even greater impact on rural growth and much depends on finding sustainable business models to encourage its spread in the poorest parts of the world.

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