International Food and Agribusiness Management Review
Special Issue - Volume 19 Issue A, 2016

Big Data and Smallholder Farmers: Big Data Applications in the Agri-Food Supply Chain in Developing Countries

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Abstract

The potential of *big data* (BD) applications in agriculture is attracting a growing interest from food and agribusiness industry players, researchers, and policy makers. Possible gains in agricultural productivity and supply chain efficiency from BD-based solutions can help address the challenge of doubling the food supply by 2050. Most of the research in this area evolves around commercial agricultural production in developed countries with relatively limited attention to BD-based solutions focused on smallholder farms in developing countries. This paper provides an overview of the existing and emerging technologies that can potentially enhance the BD application in the agribusiness value chain in developing countries, and presents a discussion of four successful cases of BD applications targeting smallholder producers. This paper also highlights drivers and barriers for smallholder-oriented BD applications in the agri-food supply chain in developing countries and discusses related implications for policy makers, private industry, and NGOs.

Keywords: big data, smallholder farms, agribusiness, ICT, Africa

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Introduction

The potential for *big data* (BD) applications in agriculture is attracting a growing interest from food and agribusiness industry players, researchers, and policy makers. The term BD is broadly defined as "high-volume, high-velocity, and high-variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision making."[1] Potential gains in agricultural productivity and supply chain efficiency from BD-based solutions could significantly enhance the ability of global agri-food systems to face the challenge of doubling the food supply by 2050. Most of the research in this area revolves around the BD applications in commercial agricultural production in developed countries. Relatively limited attention is given to the potential of BD-based solutions in the agri-food value chains in developing economies (Kshetri 2014).

The restricted access to resources and markets faced by smallholder farmers in developing countries is often cited as the main barrier for adopting new technologies and developing new capabilities that are necessary for successful BD based solutions (Jack 2013). However, two important factors should be considered when assessing the potential of smallholder farm-oriented BD applications: (1) smallholder farms in developing countries are cultivating significant areas of farmland and are responsible for the majority of the local food supply in the most rapidly growing[2] regions of the world (Salami 2010); (2) the adoption of Information and Communication Technologies (ICT), in particular mobile-cellular and mobile-broadband connection, in developing countries is growing at a remarkably rapid rate. The combination of these two factors provides unprecedented opportunity for mass mobilization and aggregation of information and data on the smallholder farm level in developing economies. This in turn creates an enabling environment for BD applications that can benefit smallholder farmers and enhance the efficiency of agri-food supply chain.

Many new technological solutions are currently transforming a number of key industries in developing countries and creating significant but complex opportunities for BD applications with potential benefits to actors across the agri-food value chain. Therefore, there is a need to explore: 1) how the ICT growth can support the use of BD applications, 2) where and how BD is currently being used in developing countries, and 3) what are the major drivers and impediments of the adoption of BD applications. The review of the existing research in this area revealed a large gap in the academic literature related to BD applications in agriculture in developing countries. The existing documented evidence on this topic is largely limited to technical reports, proof-of-concept studies, and project descriptions. The purpose of this paper is to begin filling the gap by making the existing evidence on smallholder-oriented BD applications easily accessible to food and agribusiness scholars and decision makers.

The objectives of this paper are threefold. First, it provides an overview of the existing and emerging technologies that can potentially enhance the BD application in the agribusiness value chain in developing countries. Second, it presents discussions of successful cases and examples of BD applications in agricultural and related sectors in developing countries. Third, it highlights drivers and barriers for BD application in the agri-food supply chain in developing countries and discusses implications for policy makers, private industry, and NGOs.

[1] Gartner IT Glossary 2015. http://www.gartner.com/it-glossary/big-data/.
[2] United Nation Development Programme, World Population Prospects, 2015.

The definition of BD has evolved in the recent literature to better reflect what BD applications allow rather than focusing purely on the dimension of the information asset (volume, velocity, and variety) (Boyd and Crawford 2012, Kshetri 2014, Sonka 2014, Linville 2015). In the context of this study, we combine Gartner and Kshetri's definitions and refer to BD as data sets that (1) are of higher volume[3], (2) are of greater variety[4], (3) provide insights that were not available before, and (4) enable timely decision making for supply chain actors and policy makers. Accordingly, the assessment of BD-based solutions and their potential in developing countries can be based on two alternative approaches. The first approach involves adopting the current use of BD in developed countries as a benchmark, while the second approach entails setting the benchmark at the highest possible potential of BD use in a particular region/country. Different types of benchmarks can lead to very different sets of conclusions in the analysis of current state of, relevance, and barriers to BD use in the developing world.

This paper uses the second approach since it allows conducting a more accurate and realistic assessment without the risk of underestimating the potential of BD applications in developing countries. It presents an overview of BD applications focusing on smallholder producers in developing countries. The analysis is based on the information from a variety of sources including academic literature, policy documents, and popular media. The remainder of the paper is organized as follows: the next section provides an overview of the current state and the potential of the BD-enabling technological infrastructure in developing countries, followed by the presentation of four cases of successful BD applications in East Africa, specifically in Kenya and Uganda, as well as examples from Central America and Southeast Asia. The last section presents a discussion of major drivers and barriers for smallholder farm oriented BD solutions in developing countries and concludes with implications for the agribusiness industry and policy makers.

Big Data-Enabling Infrastructure in Developing Countries

One of the critical conditions for successful BD applications is the presence of capacity and infrastructure for generating, processing, storing, and distributing the large-volume, wide-variety, and high-velocity data. Some common elements of such infrastructure in developed countries include mobile networks, internet and social media, network devices and sensors, and satellite communication systems among others. Many of these elements are either unavailable or are not well developed in developing countries as indicated by the Networked Readiness Index, which measures the performance of 148 economies in leveraging information and communications technologies at a global level to boost competitiveness and well-being. (World Economic Forum 2015) (Figure 1). However, over the last five years an unprecedented growth of ICTs has been observed, in particular mobile-cellular and mobile-broadband subscriptions (Figure 2). While the internet penetration in developing countries remains at a relatively low rate of 35.3% compared to 82.2% in developed countries[5], the rate of increase in the number of new subscribers has been remarkable over the last decade. Between 2007 and 2015, the percent of the population in the developing world using internet increased from 1–40%. Most of the increase in internet use in developing countries is due to the rapid growth in mobile-broadband connection. In 2015, thirty-nine out of 100 people in developing countries had mobile-broadband subscriptions. Between 2005 and 2015, mobile-

[3] Compared to traditional data sets.
[4] Compared to traditional data sets.
[5] ICT Facts and Figures, 2015.

broadband use has increased thirty times. While the large proportion of increase in mobile-broadband use in developing countries is likely driven by city dwellers, the general infrastructure for mobile-broadband service in rural areas is largely present through mobile-cellular coverage (International Telecommunication Union 2014). For example, the percentage of rural population covered by a mobile-cellular signal in developing regions was around 80%, according to 2012 data (Figure 3).

According to 2014 data, 90% of the population in developing countries own and use a cell phone. Data from sub-Saharan Africa indicate that 63% of rural and 80% of urban households own at least one cell phone (Tortora 2013). Thus, even though sensor and satellite technologies are not broadly available in developing regions, the rapid growth of ICTs has a potential to enhance the BD-enabling environment and allow for generation, storage and analysis of large volume and greater variety of real- or near real-time data.

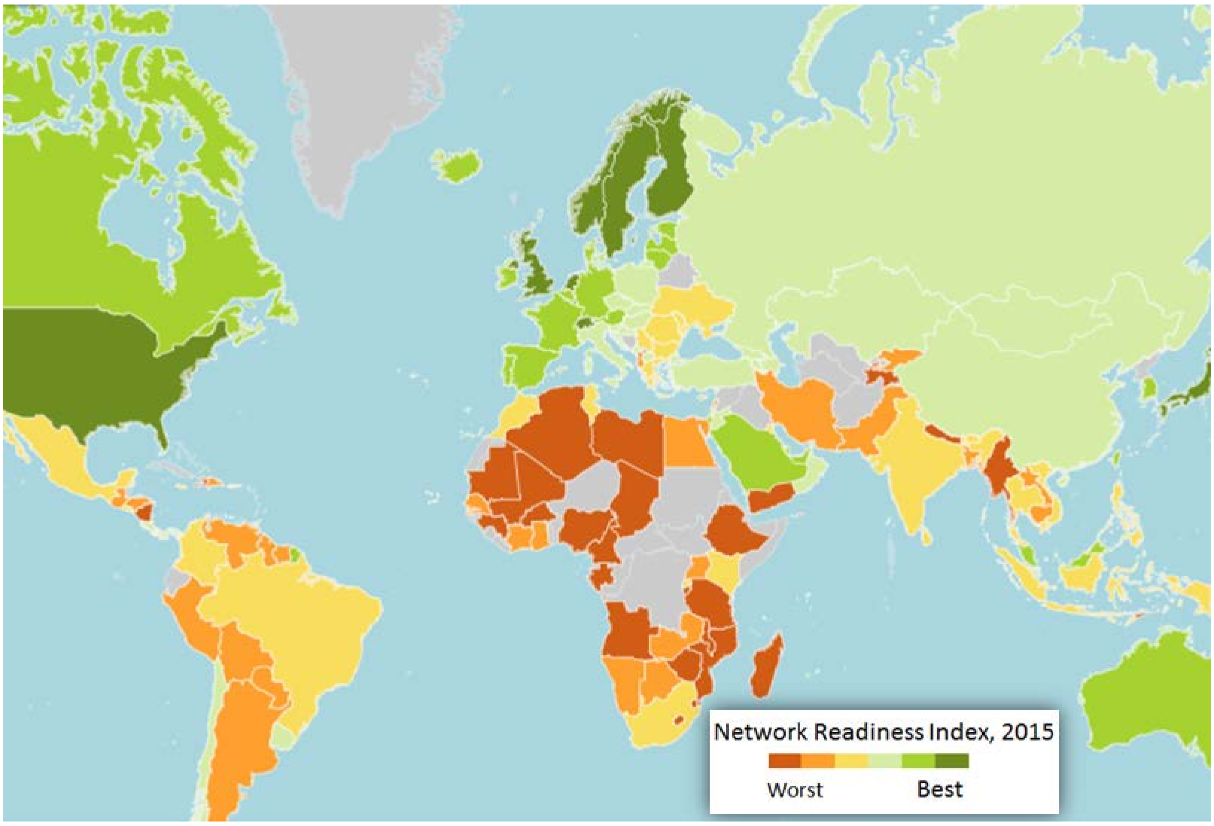

Figure 1. Networked Readiness Index, 2015.

Note. Networked Readiness Index measures, on a scale from 1 (worst) to 7 (best), the performance of 143 economies in leveraging information and communications technologies to boost competitiveness and well-being.
Source. Map by World Economic Forum, Interactive heat map of country/economy profiles, 2015.

Another element of technological infrastructure needed for storage, processing and access of BD is often referred to as *cloud computing and storage*. Cloud computing and storage technology can be simplified into two major components: (1) data centers with large storage capacity and (2) communication capabilities of broadband infrastructure for data transmission and access. The 2013 United Nation's (UN) Information Economy Report on Cloud Computing in Africa identified lack of infrastructure, fixed-broadband connectivity, and power-supply issues as problems that prevent African countries from developing and growing cloud computing. However, external stakeholders see high-growth potential in African markets and the use of shared data storage centers to achieve cost savings from economies of scale. According to the 2013 UN Report on Information Economy, 15% of co-location data centers are based in developing countries. These include seventeen centers in South Africa, one in Nigeria, and two in Kenya.

BD analysis is largely done by third-party private firms who have BD analytics capabilities and offer services to a range of private and public clients. For example, mobile network operators, such as Safaricom, and lending institutions, such as Central Bank of Africa, outsource the data analysis to private analytics firms such as Cignify and Experian for producing consumer-risk profiles. There are also instances of in-house data processing, one such example is Telenor Group - a mobile network operator providing services in thirteen markets including a number of developing countries in Eastern Europe and Asia (Aschim 2014). Most likely the majority of BD analysis will continue to be outsourced to large specialized companies due to the importance of economies of scale in this industry.

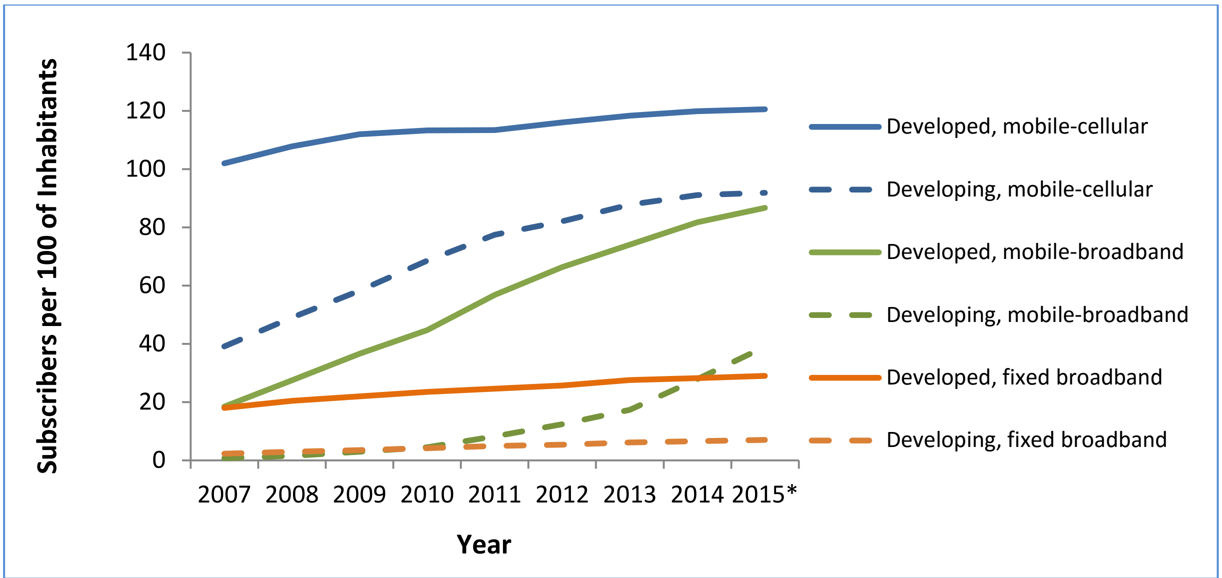

Figure 2. Growth of key ICTs in developed and developing countries, 2007–2015.

Source. International Telecommunication Union (ITU) World Telecommunication/ICT Indicators Database, 2015.
* Projected value, ITU 2015.

The ICT expansion has already had a significant impact on several key industries in developing countries including healthcare, banking, and the public service sector. In fact, in some countries these industries have been practically redefined through ICT and BD applications. For example, a BD analytics company partnered with a Mobile Network Operator (MNO) in Sierra Leone (Airtel SL) to be able to better predict the spread of the Ebola virus. The BD application was based on the analysis of call detail records (CDRs) and signaling data to predict population mobility within and around affected areas to be able to forecast the spread of the virus. This information in turn was used to help health care providers to better prepare and respond to outbreaks and medical emergencies. (Real Impact Analytics 2014). In another example from Tanzania, the BD was used to improve the availability and access to anti-malaria medicine and other critical medication by collecting real-time data via text messaging from health care providers on the current stock levels of medicine. The generated data and the insights from the analysis were used to more accurately forecast the needs and improve the delivery of life-saving medications, reducing re-stocking related incidents from 78% to 26% (Newton 2012).

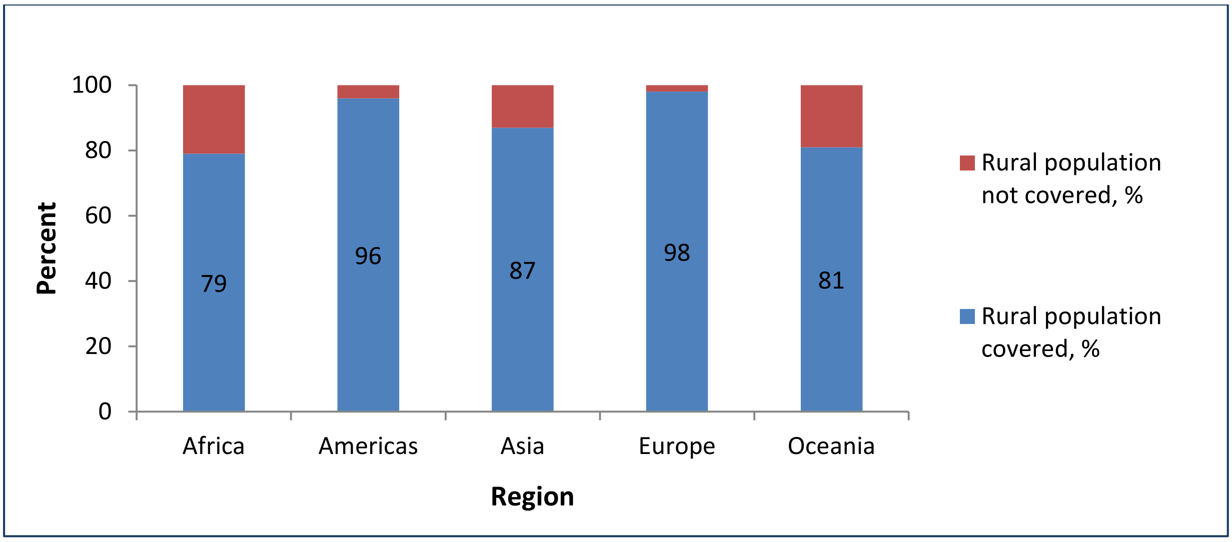

Figure 3. Rural population covered by a mobile-cellular signal, 2012.

Source. International Telecommunication Union Measuring the Information Society Report, 2014.

In Kenya, BD analytics in combination with crowdsourcing technologies allowed generating real-time information on the condition of water wells in rural areas which allowed much faster response to droughts and water shortages in remote areas (Benady n.d.). In the financial service sector, the use of ICT and mobile devices for banking services have directly impacted millions of smallholder producers in Africa by allowing them to make and receive payments with much lower transaction costs, to help better balance their cash flows within the production year, to build a credit record, and to invest in productivity (Demirguc-Kunt 2014). These and other examples of successful ICT enabled BD-based solutions in developing countries can provide important lessons and insights on the potential of BD applications focused on smallholder producers.

Cases of Successful Big Data-Based Solutions for Smallholder Farmers

Index-Based Agriculture Insurance in East Africa: The Case of Kilimo Salama

This case illustrates how BD applications enabled the design and delivery of an innovative agricultural insurance program to smallholder farmers initially in Kenya, and later was extended to Rwanda and Tanzania (International Finance Corporation n.d.). Kenya is a country of 44.9 million people in East Africa with more than 75% of the population making a living by subsistence farming (Salami 2014). Agriculture in this country as in many other developing regions is characterized by large numbers of smallholder farms and continues to be the major source of employment and livelihood (Gollin 2014). Thus, public and private initiatives focused on improving smallholder farm productivity and profitability are widely considered the key for ensuring food security and long-term economic development.

Agricultural policy makers and the agribusiness community have long recognized the importance of effective risk-management tools. This is especially true for Kenya and other developing countries where resource-constrained smallholder farmers are particularly susceptible to adverse weather events and economic shocks. However, many past attempts to design and deliver crop insurance products to smallholder farmers in developing countries, including Kenya, have proven to be economically and operationally inviable. Specifically in

Kenya, the traditional insurance plans designed to cover smallholder farm output required agents to travel to the site to evaluate the condition of the crop and to assess the damage. The combination of poor road infrastructure and the large number of remote farm locations made this system too costly for both the insurer and the farmer (International Finance Corporation, Ideas42 n.d.). Additionally, this type of output-based insurance product created corruption and fraud risks as it was practically impossible to oversee interaction between individual agent and client. Lastly, there were significant trust issues due to the lack of effective enforcement mechanisms and incidents of non-payment of indemnities by insurance companies (Cole 2013). All of these conditions made it difficult for insurance companies to establish lasting relationships with farmers and led to a rapid drop in the participation rates and ultimate failure of traditional insurance programs.

Recent developments in ICT and the widespread adoption of mobile communication in Kenya presented unprecedented opportunity for innovation in the field of agricultural insurance targeted towards smallholder farmers. The opportunity was recognized and seized by UAP Insurance, a large insurance company in Kenya which in partnership with the Safaricom, the largest mobile network operator in the country and Syngenta Foundation for Sustainable Agriculture (SFSA) developed and launched a new agricultural insurance product for smallholder farmers (International Finance Corporation n.d.). The insurance product, called Kilimo Salama[6], was designed to help farmers manage the risks from rainfall variability by covering farmers' inputs rather than outputs and using the data-driven objective index to determine indemnities therefore eliminating the need for traditional subjective evaluation by the loss adjuster (Farming First 2013). Additionally, the partnership with Safaricom allowed UAP and farmers to carry out all transactions/payments via cell phone technology, which significantly reduced the cost of the program delivery, and allowed extending the product to a larger number of smallholder farmers in remote areas.

The insurance company installed satellites and state-of-the-art weather stations in regions where it offered the product to collect and transmit weather data such as rainfall level, wind speed, and temperature to the Kilimo Salama cloud-based server every fifteen minutes (SFSA 2014). The real-time weather data was transmitted to the central location where it was combined with the regional level historical climate and crop yield data and processed using Syngenta's analytical models to estimate indemnities. The minimum rainfall level (also referred to as a "trigger level") was calculated for each specific region using thirty-year climate and crop yields data in that particular region.

The Kilimo Salama pilot program, using two weather stations, was launched in 2009 with 200 farmers who purchased the product. The following year, the participation rate had gone up to 12,000 farmers in a much wider area with twenty-five additional weather stations. In 2013, the product insured 187,467 farmers in three countries (Kenya, Rwanda and Tanzania), and the company plans further expansion in Zimbabwe, Nigeria, Ethiopia, Ghana and Uganda by 2016 (International Finance Corporation n.d.). The product quickly gained farmers' trust because having the weather insurance not only protected them from significant economic losses, but also improved access to credit, encouraged investments in high-productivity inputs, and increased production efficiency. The January 2014 Kilimo Salama's Review shows that farmers who purchased weather insurance invested 20% more in their operations and generated 16% more income than those operators who were not insured. Access to insurance allowed farmers to be qualified for micro-loans (177,782 farmers -or 97% of

[6] Translated from Kiswahili, Kilimo Salama means "Safe Agriculture".

insured operators- received loans totaling $8.4 million) which were not available to them in the past (SFSA 2014).The product was a success for UAP since the company was able to (1) develop a more objective measure due to generating weather data and using it to determine indemnities, (2) reduce the program delivery cost and thus improve supply chain efficiency in delivering this product, and (3) build trust with farmers (International Finance Corporation, Ideas42 n.d., World Farmers' Organization n.d.). Additionally, UAP's insurance served as an indirect coverage for microfinance institutions (MFIs) by protecting their debtors—smallholder farmers. Thus, this BD-based risk protection effectively helped farmers to improve their loan eligibility and their ability to invest in production.

The use of mobile phones to develop and deliver an effective insurance product in Kenya impacted multiple stakeholders. From the insurance company's perspective, this solution enhanced product design which in turn improved efficiency in product delivery and reduced the cost of delivery. From the smallholder farmers' perspective, the new risk management tool helped them to become more financially resilient to weather shocks. In countries like Kenya, the aggregate impact of such a risk management tool can be very high since rural communities are composed of many smallholder farmers (World Bank 2014). This case provides a good illustration of how an ICT enabled risk management solution was made possible through a collaborative effort of various stakeholders and significantly enhanced smallholder agricultural production and food security in the region. While this case does not present a direct application of BD, the ICT-based insurance solution contributes to the BD infrastructure by establishing a capacity for the generation of large volumes of wide variety, real-time data that can be used by multiple stakeholders (such as micro-finance institutions and input suppliers) to enhance efficiency throughout the supply chain.

Big Data Based Solution for Enhancing Financial Inclusion of Smallholder Farmers: the Case of M-Pesa and M-Shwari in Kenya.

This case illustrates BD applications designed to enhance smallholder farmer's access to credit. The application was developed and implemented through a partnership between mobile network operators (MNO), data analytics companies, and financial institutions. The joint initiative made it possible to use individual telecommunication and transaction data to develop a credit scoring system for smallholder farmers in Kenya. According to the World Bank's 2014 Global Findex Database, in 2011 about 2.5 billion people in the world did not have a bank account and thus were unable to save, borrow, or transfer funds outside of cash transactions. The limited access to banking services and credit has been shown to impede smallholder farm's productivity and growth (Foltz 2004).

The recent widespread adoption of mobile communication had a dramatic impact on smallholder banking in sub-Saharan Africa, enhancing transaction efficiency and trade in the agri-food sector (Ogbeide and Ele 2015). Introduction of mobile money accounts expanded financial inclusion providing 64 million people the ability to use banking services for conducting transactions, borrowing funds, and saving. For approximately half of these mobile money account holders, mobile banking is the only way to access banking services because traditional banking services are not available in many remote areas (Demirguc-Kunt 2014).

The new modes of payment through mobile technology not only significantly reduced transaction cost for smallholder farmers but also generated large volumes of data on transactions by millions of individual farmers. The data on millions of smallholder farm sales volume, price, transaction date, frequency, and payment history which was practically impossible to track and record in the past became abundant due to mobile banking. The BD analytics capabilities made it possible to analyze the mobile banking data and to assess individual smallholder farmer's credit risk profiles and borrowing/repayment capacity. This in turn created an unprecedented opportunity for financial institutions to extend banking and credit services to agricultural producers who were credit constrained due to the lack of credit history.

In sub-Saharan African countries, and in Kenya in particular, the mobile network operators were the first to realize the value of extending financial services to the unbanked population and using it as an additional revenue stream. Groupe Speciale Mobile Association (GSMA), the association of mobile operators and related companies, with the financial support from the Bill and Melinda Gates Foundation and Rockefeller Institute, launched the industry-wide initiative called mAgri which focuses on using the available ICTs to enhance the quality of life of smallholder farmers. Two of the program's most important components are Agricultural Value Added Services (AgriVAS) and Agricultural Mobile Finance Services (AgriMFS) (GSMA 2015).

AgriVAS offers a number of agricultural value-added services such as agronomy information and advisory services via mobile phone to farmers in remote areas. The information is transmitted via text messages and the cost of which is billed to customers. The program is well aligned with the goals of the MNOs as it helps them to: (1) retain and enhance loyalty of existing customers by offering new services that help enhance their yields, (2) attract new customers and (3) enhance revenue stream from text messages. As a result, the project began to generate large volumes of data from client call detail records (CDRs) which were matched with demographic information provided at registration. This provided initial BD infrastructure to launch mobile money programs, such as Agri MFS. These programs generated streams of new user-level data on agricultural transactions and a potential for BD application in this area.

Historically, the absence of credit risk profiles and payment history were the major obstacles faced by financial institutions in their efforts to extend credit products to smallholder farmers. However, the new data generated from AgriVAS and AgriMFS provided an unprecedented opportunity to team up with MNOs to design innovative digital financial services focused on smallholder agricultural producers. Among the most notable digital financial services were M-Pesa and M-Shrawi, introduced in Kenya by Safaricom, Kenya's leading mobile network operator. It successfully launched M-Pesa—a mobile money transfer service which is used by more than two-thirds of adult Kenyans, has more than 80,000 agents, and processes $20 million in daily transactions (Cook 2015). The rapid adoption rates created an opportunity for Safaricom to introduce new banking products to the segment of their clients who were previously unbanked but now gained access to major financial services via mobile phone.

M-Shwari was launched in Kenya in November 2012 through a partnership between Central Bank of Africa (CBA) and Safaricom, and offers a combination of savings and loan products. With these new products, clients were able to borrow and repay funds using mobile phones and thus manage their cash flows and savings more efficiently. The M-Shwari is an account managed by CBA, but the transactions are made through the M-Pesa wallet. As of December 2014, M-Shwari extended a total of 20.6 million cumulative loans to their clients and disbursed $277.2 million (Cook and McKay 2015). This product is an example of a BD-based solution used by MNOs and financial institutions in developing countries to accurately determine the loan size and terms of borrowing for smallholder farmers.

The technology used by mobile operators allows for generation of two categories of real time dynamic data: (1) telco, which includes data on demographics, location and mobility, source, and destinations of calls; and (2) payment information, which includes financial information such as payments sent/received, and airtime top-ups. The MNOs collect the data and outsource the analysis to data analytics companies. The results of the analysis are then transferred to the financial institution to make appropriate decisions on loan approval. Three companies—Signify, Experian, and Real Impact Analysis (RIA) - are some of the largest data analytics companies that operate in the developing countries as an intermediary between the lending institutions and the mobile network operators and estimate credit risk profiles for clients using the data generated by MNOs and their predictive models. Recently, some MNOs (e.g., Telenor Group) considered transferring this function in-house to ensure that (1) the data of their clients is secure and protected, and (2) they can access the information at any time. Processing and analyzing BD requires significant investments in resources and capabilities but can provide leverage when negotiating the terms with the financial institutions.

M-Shwari analyzes clients' credit-worthiness and assigns credit limits using an algorithm based on customer use of Safaricom services (Cook 2015). The variables used in the algorithm are telecommunication data including airtime and airtime credit based on the Safaricom's datasets, as well as, the use of M-Pesa and the length of time as an M-Pesa customer. The real-time nature of the data being collected from the clients allows re-evaluating clients' payment performance and adjusting the loan size and terms of borrowing very promptly. The latter in turn makes borrowing more efficient while reducing the probability of a non-performing loan (NPL).

This illustrative case of a BD-based financial solution contributes to the overall objective of this paper in three ways. First, it shows how the growth and development of ICTs enabled the utilization of BD in the banking and financial sector. Second, the case illustrates the ability/potential of BD to develop and deliver products/services to remote smallholder farmers otherwise inaccessible due to poor physical infrastructure and high transaction costs. Third, it shows how the BD-based solution enabled lending institutions to extend credit to smallholder farmers who otherwise would not have access to it due to the absence of individual credit history.

Enhancing Smallholder Farmers Access to Market Information through Big Data Applications: The Case of AgriLife in Kenya and Uganda

The case of AgriLife in East Africa is an example of successful use of a BD-driven platform to improve access to market information and reduce inefficiencies in the agri-food supply chain by connecting multiple stakeholders. Uganda is an east African country with a population of 37.6 million, 80% of which are living in rural areas and deriving their livelihoods from agriculture. The country's economic development has been constrained significantly by many factors including the lack of appropriate transportation and communication infrastructure. Recently, mobile phone technology was rapidly adopted and widely used by Ugandans. In 2014, Uganda's communication commission reported 19,506,550 subscribers of mobile phones which is a 10% increase from 2013. The rapid adoption and widespread use of mobile technology generated large volumes of a wide variety of real-time user level data, opening up a possibility for BD applications in a range of industries including agriculture. The potential value for the agri-food sector from such BD applications was recognized by both public and private sectors leading to the development and launch of several public-private initiatives in this area.

Approximately 47% of Ugandans have access to financial services including mobile-based and traditional banking. The number of Ugandans using mobile money services is four times greater compared to those using exclusively traditional bank accounts. In Kenya, 65% of the population has access to ranking/financial services, more than half of which have only mobile money accounts (InterMedia Financial Insights 2014). The high rate of mobile technology adoption in the communication and banking sector established an initial BD generation and aggregation infrastructure enabling development of a larger integrative platform for connecting millions of smallholder farmers with financial institutions, buyers, input suppliers, and agricultural service providers.

One such platform was developed and launched by Mercy Corps, an international development organization, in Uganda (CTA 2014; Jimenez 2013). With the financial support of Swiss Agency for Development and Cooperation, and in partnership with MobiPay (Kenya-based IT-company), Mercy Corps developed a mobile-based platform called AgriLife. The purpose of AgriLife was to bring all of the stakeholders along the agribusiness supply chain into an integrated data driven system in order to meet smallholder farmers' needs faster and more effectively (MercyCorps 2015). The platform facilitates steps in the BD application process including: (1) collection of near real-time data on farmers' production capability and history, borrowing/repayment potential, and input use, (2) data analysis and projection of future production capacity, demand for inputs and credit, and (3) data integration across supply chain to identify farmers' needs more accurately and deliver resources to distant farmers in a more timely manner (Technical Center for Agriculture and Rural Cooperation 2014). Due to new capabilities offered by this platform, in two years, more than $2 million was extended to about 120,000 distant smallholder farmers in Kenya and Uganda in revolving credit lines (Kshetri 2014).

The developers of AgriLife found building long-lasting trusting relationships with farmers to be one of the key factors in attracting farmers to join the network. They partnered with farmer-centric agribusiness enterprises (e.g. farmer cooperatives, producer associations) to reach out to farmers via entities which already have established trust and reputation with farmers. To be part of the platform, farmers need an active mobile phone and a subscription. Once subscribed, farmers are able to transact with farmer-centric enterprises via mobile phone at significantly lower transaction costs. The farmer-centric enterprises collect data on farmers' production history, input use, etc. via mobile phone and share the data within the platform. MobiPay data analytics experts use the generated data to project production capacity, predict demand for inputs, estimate borrowing capacity and develop credit risk profiles. This information is then used by lenders and input suppliers to supply products/services more efficiently to smallholder farmers.

The use of this platform provides a number of benefits to agri-food supply chain actors. First, by sharing their production, demographic, and transaction data, farmers are able to signal to input suppliers, lenders, and buyers about their production potential and need for credit and other inputs. Second, input suppliers are able to identify and more accurately estimate the demand for their products and services. Third, financial institutions can use the credit scores, payment history, and production data provided via this platform to develop and offer more targeted financial services to the broader customer base. This is an illustration of how the BD application can facilitate transactions in the agri-food supply chain by enhancing access to market information.

Linking Smallholder Farmers in Central America, East Africa, and Southeast Asia to Export Markets through a Cloud-Based Transactional Platform: The Case of FarmForce

The use of various out-grower schemes aiming to connect smallholder fruit and vegetable growers with export markets are becoming a commonly observed phenomenon in developing countries. However, the increasingly stringent global trade protocols with strict traceability requirements have created unfavorable conditions for smallholder farmers who lack necessary resources and capabilities for investing and implementing effective traceability programs (Feed the Future 2014). Consequently, there was a need for an innovative solution for enhancing farmers' ability to meet export market standards and certifications while at the same time ensuring a more stable and predictable supply of good quality produce for exporters (Jimenez 2013). Syngenta Foundation for Sustainable Agriculture -SFSA- (with co-investor, State Secretariat for Economic Affairs of Switzerland, and partners, Global GAP and MercyCorps) provided such a solution through a BD application called FarmForce.

FarmForce is a cloud-based mobile application which allowed farmers and field staff to enter the real-time production data which was then directly transmitted to the exporter's server and analyzed for further management, logistics, and distribution decisions. The platform was first introduced in East Africa (Kenya 2012) and then expanded to Central America (Guatemala, 2013) and Southeast Asia (Farmforce n.d.).

In Guatemala, a private horticulture exporter, Fair Fruit, signed up with FarmForce in 2013 to improve its grower management capabilities. Before having access to this product, the firm experienced difficulty with efficiently collecting information (Global G.A.P. 2014) which could negatively impact smallholders (if their produce does not meet the food safety requirement) and the exporter (if unable to ensure a stable supply of produce). In 2012, Fair Fruit enrolled only 16% of its farmers, but by 2014 it extended subscription to all of its smallholders (FarmForce n.d.). Some of the benefits of using this platform include the improved knowledge of the farmer profile (information on personal profiles and location that was difficult to obtain in the past) and the high efficiency of information transfer between the head office (Fair Fruit) and field staff/farmers (Global G.A.P 2014).

Discussion and Conclusion

In both developed and developing countries BD applications in agriculture are largely driven by the desire to improve productivity and profitability of firms along the agri-food supply chain. However, BD applications in the developed world are primarily focused on enhancing the productivity and efficiency of large-scale commercial agriculture, while BD-based solutions in developing countries have been largely focused on addressing systemic problems and market failures along the agri-food supply chain. Consequently, there are also significant differences in the nature of the opportunities and challenges for BD applications in developed and developing world.

One of the primary drivers of BD-based solutions in developing countries is the rapid advancement of ICTs, specifically decreasing the cost of data storage, growing mobile-cellular coverage in rural areas, and increasing use of mobile phones even among the most resource-constrained smallholder farmers. While the mere collection of smallholder farm data through ICTs would not constitute BD, the data generated through the use of mobile phones is uniquely detailed and in combination with additional supplemental information can produce significant benefits for agri-food stakeholders through ex-post analysis, real-time measurement and feedback, as well as future prediction and planning. For example, the presented cases illustrate how the ex-post analysis of cellphone-generated transaction data can provide otherwise unattainable insights on creditworthiness of millions of individual smallholder farmers. The cases also illustrate how the analysis of real-time spatial and temporal data from transactions using SMS and other value-added services can result in more accurate assessment of access to input and output markets, spread of animal and plant diseases, as well as in the delivery of timely alerts and mitigation assistance. Further, the relatively high inter-comparability of the format of mobile-cellular data produced and held by different telecommunication operators provides a significant scaling potential and the ability to improve accuracy of predictive analysis of crop yields, food supply and demand shocks, and potential food security risks. This is consistent with key features of the BD definition, namely (1) high volume, (2) greater variety, (3) generating previously unavailable insights, and (4) enabling timely decision making by supply chain actors and policy makers.

Another key enabling factor for smallholder-oriented BD applications is the growing number of collaborative win-win solutions mutually beneficial for both public and private sectors. The private firms are the primary drivers of BD applications in the developed world, while in the developing countries many BD solutions are launched through public-private initiatives with the support of NGOs and international development agencies. For example, as highlighted in the Kilimo Salama case, the new agricultural insurance product was developed and extended to farmers through collaboration between the private mobile network operator Safaricom, large insurance company UAP, and a non-profit Syngenta Foundation for Sustainable Agriculture. In the examples of BD based solutions for financial inclusion and market information problems in Kenya and Uganda, the applications were designed and implemented through a collaborative effort of a variety of stakeholders including private MNOs and data analytics firms, micro-credit institutions, and development agencies such as the United Nations and World Bank. With the growing awareness about potential benefits of smallholder-focused BD applications, there is an increasing realization of advantages of public-private partnerships in exploiting that potential in developing countries.

Moving forward, the international development community, governments, and the agri-food industry will have to direct significant effort to overcome a number of important challenges and barriers in order for benefits from smallholder-oriented BD applications to fully materialize. Some of the key barriers include availability and accessibility of data, standardization and interoperability of BD analytics, data privacy and security concerns, as well as underdeveloped legal infrastructure for governing the sector (International Telecommunication Union 2014; Naef et al. 2014). Many specialists in BD strategy who point out the rapid growth of data generation in the developing world also emphasize the importance of data sharing (Rijmenam 2015). According to the World Economic Forum's report Big Data, Big Impact (2012), emerging markets use a much narrower set of technologies for data collection compared to industrialized countries; however, they are able to generate about 2.5 quintillion bytes of data every day, and the annual growth of mobile-generated data is expected to exceed 100% through 2015. The report also emphasizes the need to establish BD alliances in the developing world to capture gains from synergies in collective capabilities and to tackle the issue of wide digitalization gap between developed and developing countries (World Economic Forum 2012). Sharing data with other stakeholders can create large potential benefits due to network effects and economies of scale and scope. However, it also raises concerns about data privacy and security. Thus, the successful application of BD is conditional on not only the presence of technological infrastructure, but also the adequate legal infrastructure.

This paper provides an overview of the current state, growth potential, and key drivers of the ICT adoption and potential utilization in BD applications in developing countries. The analysis of four illustrative cases of smallholder-oriented BD applications suggest that the rapid advancement of major technologies such as mobile phones and cloud-based technology have a potential to create favorable data collection and aggregation infrastructure for further development of BD applications in developing countries. The stronger focus on ITC in some of the cases is driven by the important enabling role of ICT for BD applications in the context of developing countries. As evidenced by the case studies, this rapidly growing technological infrastructure enables development of BD based solutions to systemic failures in the agri-food supply chain in developing countries. Moving forward, there is a need for more research by agribusiness and development scholars in order to gain insights on drivers and impediments of innovative BD based solutions to study or assess problems faced by smallholder farmers. This is an important gap to fill since the BD can unlock the agricultural production potential of smallholder farmers and significantly enhance food security in regions with low economic development and high population growth.

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