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The Challenge of the Digital Agricultural Revolution: A Comparison Between Advanced Economies and Developing Countries

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THE CHALLENGE OF THE DIGITAL AGRICULTURAL REVOLUTION: A COMPARISON BETWEEN ADVANCED ECONOMIES AND DEVELOPING COUNTRIES

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THE CHALLENGE OF THE DIGITAL AGRICULTURAL REVOLUTION: A COMPARISON BETWEEN ADVANCED ECONOMIES AND DEVELOPING COUNTRIES

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ABSTRACT

The new digital technologies offer remarkable opportunities to make agriculture more sustainable and contribute to the amelioration of inequality at the local and global level. And yet, digital innovations and, in particular, the adoption of platforms risk creating further distortions among and within countries.

Digitalization could contribute to the further concentration of agriculture in a few giant firms and also lead to the rapid and unmanaged demise of subsistence farming as it is typically practiced in developing countries. Alternatively, if the implementation of the digital technologies is guided, they could help achieve sustainable development goals by increasing productivity, while reducing waste, pollution, and inequality in agriculture.

The development banks can, with their investment and stewardship, facilitate an inclusive and sustainable digital revolution in the agrifood sector at global level. In this report, we summarize the current situation in regards to digitalization and the adoption of platforms in agriculture in both the developed and developing countries.

1. INTRODUCTION

The inclusion of digital technologies and thus, software into every part of social and economic life is having profound impacts on all aspects of the agrifood system in the developed and the developing world. These offer enormous potential to address the United Nations' Sustainable Development Goals (SDGs), even as they shift power and flows of value in ways that will impact the organization of the agrifood system and the livelihoods of agriculturalists and those in the agrifood value chain (Kenney et al. 2020). In this report, we explore the trajectories of digitalization with respect to their impacts on agriculture. The report takes a farm-centric approach and thus only briefly mentions other dramatic changes that are underway, in particular, the transformations between final consumers and supermarkets and restaurants. It is important to note the COVID-accelerated entry of vendors such as Amazon into the food retail and distribution system (for an overview of these changes, see Kenney and Visser 2021), which will almost certainly eventually affect farmers. Finally, the impacts of digitalization will differ dramatically between developing and developed countries, smallholder[1] and commercial farmers, and by crop (see, e.g., Maru et al. 2018).

At the global level, agriculture is an enormous undertaking and has a powerful impact on the environment as well as human health and well-being. In value terms, it constitutes only 3.55% of global GDP, though its impacts are far bigger. While dropping rapidly, in 2020 28% of the world population was still employed in agriculture; in developing countries, these are among the poorest citizens and even in developed nations, farm laborers, often immigrants, are among the poorest in their society. In contrast, it is estimated that food value chains contribute to 19-29% of all global greenhouse gas emissions (FAO 2015). Moreover, agricultural chemical use and runoff contribute significantly to the global safe water crisis. These facts alone suggest that agriculture, both commercial and small holder, has a vital role to play in any transition to a more sustainable society. The application of digital technologies to agriculture can increase the value created in agriculture and help address the UN SDGs (United Nations DESA 2017).

Digitalization has the potential to help agricultural systems more productive, efficient, socially inclusive, transparent, traceable, and resilient while reducing costs, waste, production losses, and agrichemical use (FAO 2017; 2019). The promise of "precision" or "smart" agriculture as a transition from industrial agriculture where chemicals were applied uniformly to an entire field to one in which chemicals are applied only where needed (variable rate technologies). Digital technologies also can allow farmers to discover and connect directly with their customers, thereby decreasing the role of intermediaries and potentially reducing the distance food must travel (Wilson et al. 2020) and food waste (Annosi et al. 2021).

Yet, as with any powerful new technology, digitalization could also result in a reinforcement of the current technological and economic trajectories, resulting in greater concentration, increased inequality, and potential joblessness in both developed and developing agrifood systems (Klerkx and Rose 2020). Of particular concern is that digitalization could centralize data in a few firms that could then exploit the other parties in the value chain. Adoption could operate to recast the linkages in the agrifood system and thus affect farmers in ways that might exacerbate inequality and increase the concentration of power in a few firms (Birner et al. 2021; Kenney et al. 2020; Prause et al. 2021).

1 Small holdings are usually farms supporting a single family with a mixture of cash crops and subsistence farming. As a country becomes more affluent, small holdings may not be self-sufficient, but may be valued for the rural lifestyle (Wikipedia 2021).

Our study suggests that the goals for the future evolution of agriculture and for agtech should be to deploy technology in ways that underpin sustainable development in communities and does not damage current actors in the agricultural sector, though change always has costs and risks. The challenges will be to avoid concentration and domination for narrow goals by the already enormous agricultural industry incumbents and also existing platform giants (i.e., prevent increased monopolization and the loss of smaller farmers). The current wave of entrepreneurship and innovation funded by venture capital is remarkable in its size and breadth, however many of these firms, if successful, are likely to be purchased by industry incumbents or platform giants.

To prevent increased monopolization and concentration and ensure equity and sustainable development in this arena it will be necessary for the development banks to work with communities, as a whole and to define how agtech can meet the UN SDGs. It will also be important to foresee the challenges in the planning and investment process. When funding technologies and platforms, it is vital to ensure a long-term perspective and to exercise care regarding how infrastructure funded with public monies is used by private actors, so that development bank funding does not increase the exploitation of farmers in either developed or developing nations.

The paper begins with a discussion of the unique features of agriculture that problematize the adoption of digital technologies. This is followed by an exploration of the digitalization and digitally-enabled technologies generally. We then discuss the differences between developed and developing country agriculture with particular attention to smallholders. We then discuss the enormous amount of venture capital being invested in digital agriculture technologies with the intention to disrupt the entire sector. This is followed by a discussion of the organizational experimentation underway on the introduction of online platforms to reorganize agriculture. We then reflect upon policies that development banks could adopt to ensure that investments they make in agtech and in support of platform strategies for agriculture will support communities and agriculturalists by foreseeing the outcome and dynamics of the technologies being funded. The conclusion returns to larger themes raised in the paper.

2. AGRICULTURE AS AN INDUSTRY IN THE AGRIFOOD SYSTEM

Agriculture as a sector has many unique features that make it different from other industries. First, it is not a single industry, but rather each crop should be understood as a separate industry with its unique value chain for inputs and outputs. Thus, the dynamics and adoption of digitalization within each crop is different, i.e., corn grown for animal feed is different from sweet corn, as are strawberries, as is processing and slicing tomatoes, apples, coconuts, palm oil, milk, beef, and hundreds of other crops-all differ. Crop production is embedded in different social milieus with their different capital intensities, labor relations, and value chains. For example, rice production in Texas or Arkansas differs not only from smallholder rice agriculture in Java as well as from highly mechanized small farms in Japan. Time and timing are critical for farming success. The farmer must invest in planting and wait until harvest to secure income. Further, the mature crop often must be gathered during a narrow window, which means demand for labor is variable and capital goods such as equipment may only be used during narrow time windows[2]. Farmers are dependent upon biological processes that are affected by any number of natural phenomena over which the agriculturalist has little control. These include a remarkable variety of pathogens including viruses, bacteria, fungi, and larger animals. Weather phenomena such as too much or too little rain, too cold or too hot, too much or too little humidity etc. affect plants and animals. Even in controlled environments, pathogens can ravage production-this is true in both developed or developing countries. In other words, the outcome of the farmers' investments is, in part, not under their control.

The final irony is that the price of the final product is uncertain and dependent upon demand that is affected by the success and/or failure of other farmers. The greater the success of other farmers in terms of yield, ceteris paribus, the lower will be the incomes of all. Moreover, market demand continually changes the product price.

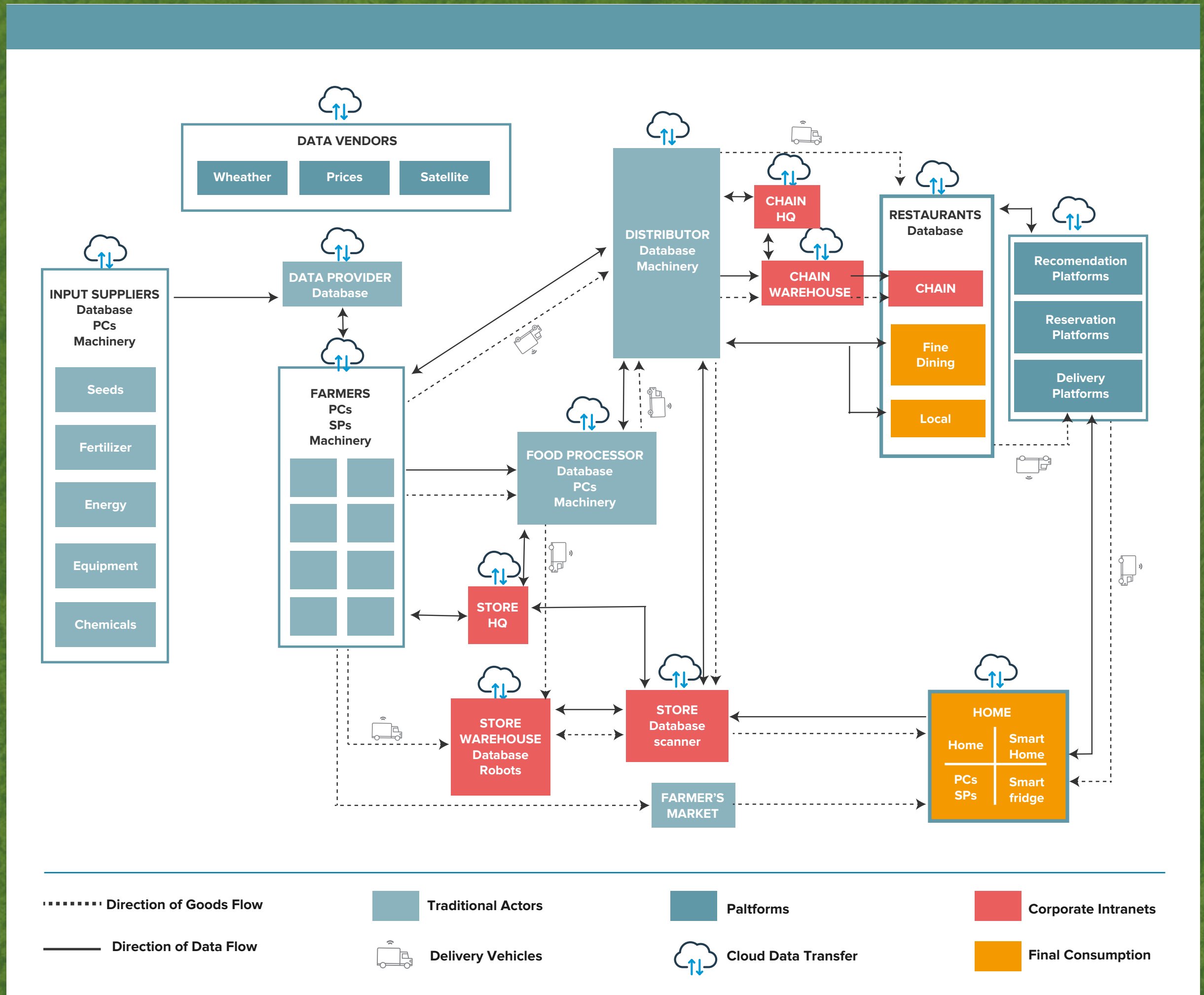
Given this environment, farmers, who may be one bad crop away from bankruptcy, are inherently conservative as they are reluctant to adopt innovations that increase risk or uncertainty because downside losses can be catastrophic[3]. Given the uncertainty, innovations that provide better information to make better business decisions are rapidly adopted-be they the Farmers' Almanac, personal computing, or improved commodity price and weather information.

Farmers, whether in developed or developing countries, are embedded in value chains. Moreover, with few exceptions, such as plantation crops, the farmers are the smallest businesses in the chain (see Figure 1 for a stylized depiction). To illustrate, even small holder farmers (SHFs) buy inputs such as agricultural chemicals, seeds, and farm equipment from local dealers that are selling inputs produced by large, and, sometimes, enormous oligopolistic agri-input multinational firms (Sexton and Xia 2018). Similarly, farmers must often sell to powerful and, very often, oligopsonistic intermediaries that include distributors, food processors, or retailers (on concentration in the agrifood system, see for example, Clapp 2021).

2 In contrast to industry where a machine can be used year-around, much of the farm equipment sits idle for long periods. This means that the amortization of capital equipment is "lumpy" as it cannot be used year around.

3 Many governments recognize these dangers and thus provide crop insurance and other support. Obviously, in developing nations there may be less such downside risk mitigation particularly in small-holder agriculture.

FIG. 1 | STYLIZED DEPICTION OF A AGRIFOOD VALUE CHAIN, [2021]



Source: Kenney et al. 2020

Firm size and location are crucial variables for understanding the evolution of the agrifood industry. As a generalization, from 1960 to 2000, average farm size decreased in most low- and lower-middle-income countries, whereas it increased in some upper-middle-income countries and in nearly all high-income countries (Lowder et al. 2016)-a trend that has continued in high-income countries such as the USA (USDA 2021). These divergences suggest that agriculture digitalization will differ between low- and high-income countries, as the larger farms will, almost certainly, be the first to adopt the more sophisticated digital technologies, many of which are embedded in capital goods equipped with the most sophisticated sensors and computers.

3. DIGITALIZATION OF AGRICULTURE

Invariably, major technological developments affect the relationships between businesses, social actors, and labor and capital. The ongoing innovation in, and adoption of, digitalization has led to an outpouring of writings on the future of work that is remarkable in terms of volume and scope. Some suggest that digitalization based on improvements in computing and software, including artificial intelligence applications (AI) and big data, will dramatically increase unemployment (Brynjolfsson and McAfee 2014; Frey and Osborne 2017). Even those that are less apocalyptic suggest that there will be dramatic shifts in work and employment (see, e.g., Manyika et al. 2017).

The scope and complexity of the digital technologies that will affect agriculture can only be understood by considering their ubiquity. To illustrate, a modern automobile contains more than 3,000 semiconductors, which suggests that a modern tractor is likely to have that many or more (Ewing and Boudette 2021). Similarly, in 2020 it was estimated that 40% of the value of a modern car was in its electronics including parts and software (Tingwall 2020); this is certainly the case with farm machinery. In Table 1, we list some of the most important digital technologies, their farm applications in developing country agriculture and also for SHFs in developing nations. For the most part, only SHFs have access to digitalization through their feature or low-quality smartphones. Unfortunately, coverage of rural areas by carriers remains limited.

TABLE 1 | DIGITAL TECHNOLOGIES AND FARM APPLICATIONS, [2021]

Technology	Functions	Effects	Developed Country Usage	Developing Country Smallholder Usage (ex-China)
Digitized machinery	Greater accuracy, Capable of	More efficient operation, save labor	Widespread adoption	Not used
Drones	Field mapping, Disease recognition, Pesticide application	Decrease ag chem usage, timely response to reduce losses	Many usages, owned by farmer or contractor	Many potential usages provided by government or non-profit
Robotization	In-field and post-harvest	Save labor	Early stages	Not used
Image recognition software (smartphone app)	Identify pests, diseases, ripeness, location for picking	Improved diagnosis, decrease labor usage for harvesting or weeding	Rapidly increasing	Increasing
Digital payment systems	Payment for unbanked	Greater efficiency and speed	Increasing, but outside China not large	Significant in some countries (China, Kenya)
Digital marketplaces	Buy inputs, sell outputs	Disintermediation, lower costs or increase prices	Increasing but fragmented	Amazon and local competitors, LA - MercadoLibre; Africa - Numia
Smartphone/mobile internet	Access internet, monitor equipment, buy/sell	Improve access	Ubiquitous	Usage increasing
Smartphone network coverage	Internet access	Access cloud in real-time	Good and improving	Spotty
Big data platforms	Aggregate and analyze all data generated	Greater efficiency	Limited	Not used
QR codes	Identify things	Improved security and traceability	Increasing	Not used
Sensors (moisture, nitrogen, pests, etc.)	Monitor conditions in field in real time	Improve decision making	Increasing	Not used
GPS	Location	Improved locational accuracy	Ubiquitous	Smartphone application
Farm management software	More accurate financial and other information	More efficient operations	Ubiquitous	Not used

Source: Authors

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As Table 1 indicates, digitalization of an ever-increasing number of the activities in the agrifood system is creating ever greater flows of data that, not only, can be mined for unique insights, but also provide new opportunities for monitoring and surveillance (Zuboff 2019). These data flows are creating new intermediaries such as consultants, drone pilot firms, system integrators, etc. to create and organize this increased flow of data.4 As important, the connection of these devices, sensors, and actors to the internet results in increased transparency and the possibility of creating online platforms-a process that has already reorganized a wide variety of industries (Kenney et al. 2021).

The near universal adoption of smartphones in the developed countries, increasing access to cloud processing power, and the advent of big data permits the integration of computing power into all aspects of economic life. When considering digitalization, most observers concentrate on relatively ubiquitous products such as the smartphone (the iPhone was introduced in 2007) or tablets-these products are iconic and important. However, digitalization is far more pervasive and profound than this, as digital technologies are embedded in all manner of machinery including agricultural equipment. As Zuboff (1988) points out, the implications of this "colonization" of machines by computational capability monitor actions, thereby turning those actions into data to be analyzed. This increasing flow of data is further accelerated by rapid advances in sensor technology that make machines more capable of acting upon stimuli from the environment.

The ability of these machines to sense and interpret the environment liberates them from needing the direct control of operators. Hence, the introduction of automated milking machines, nearly autonomous tractors and combines, and variable rate chemical applicators, to name only a few sensor-laden products will result in changes in labor use and location, capital intensity, and power in the value chain.

The impact of digitalization on agriculture can be observed at three levels: micro, meso, and macro level. At the micro level, digitalization is changing the individual machines. Whether they are drones, tractors, milking machines, packaging machines in a food-processing plant, a cow with an implanted chip, or an autonomous vehicle-they all produce data that can be analyzed. However, they also change the ways within which people interact with them-they change the nature of work itself-and, of course, can make workers redundant. At the meso level, the data produced by these machines can be integrated into larger data pools on the farm, in the factory, and in the organization. The data can be integrated into cross-organizational systems, such as multi-firm supply chains and beyond. Finally, at the macro level, online platforms can be introduced to capture, organize, analyze, and use this data to optimize the entire system. At each level, questions exist as to who owns the data and how the ability to access and analyze it could transform power relationships, worker and farmer skill requirements, and ultimately value capture.

4 Helper et al. (2019) show that the increased digitalization of the auto industry has spawned an enormous industry of consultants and intermediaries to integrate the new robotic equipment.

4. DIGITALIZATION IN THE DEVELOPED AND DEVELOPING NATIONS

The digital technologies and artifacts are overwhelmingly created by and products of the developed nations and, in particular, the USA.5 We begin by arguing that the traditional distinction between developing and developed nations (when considering digital technology adoption) is no longer strictly applicable as the diversity of experiences in the developing world is important to understand. This is not to deny that there are millions of underserved small holder farmers in Africa, Latin America, and Asia. And yet, even these populations are adopting smartphones rapidly[6].

The most salient counter-example to any simplistic division between developed and developing nations is China, where the adoption of digital technologies, generally, and in agriculture specifically is advancing rapidly. For example, the integration of farmers using smartphones into direct-to-consumer platforms such as Pinduoduo is far more advanced than any similar platform in the developed world, thereby offering new sources of income.7 Pinduoduo is particularly interesting because it has a significant outreach program to train farmers on how to sell directly. For example, it sponsors "farmer entrepreneurship" online training classes taught by professionals from the China Agricultural University and the National Engineering Research Center for Information Technology in Agriculture. These classes teach farmers about smart agricultural services and equipment, pest control, sustainability, etc. (Liang and Cheah 2020: 52). The success of this program is possible because China has an enormous and extremely food-conscious, digitally-savvy consumer market. Furthermore, in the last decade, China has built a global-class logistics sector optimized for online purchasing and delivery. This is possible because the government has made massive investments in telecommunications infrastructure for the entire country. In this respect, China, while still a developing country (especially in rural areas), has built a first-world infrastructure in which smartphones are ubiquitous (Min et al. 2020; Zheng and Ma 2021)[8].

In developing countries, such as Brazil and Argentina, where corporate farmers produce for the global market, digitalization has unsurprisingly progressed significantly. To illustrate, an internet-based survey of Brazilian farmers found that nearly 80% had internet access and nearly 60% used apps and platforms to access information. Moreover, approximately 20% used apps for management and, similarly, 20% used global positioning systems and data and images from remote sensors (Bolfe et al. 2020). These results suggest that in developing nations' industrial agricultural regions, as a generalization, the use of digital technologies is similar to that in the developed world. Furthermore, countries such as Brazil have large-scale research and extension programs that assist these farmers in adopting digital technologies (Bolfe et al. 2020).

5 It is important to add that many of the raw materials that are used to make our devices are sourced from developing countries and their assembly is undertaken in developing countries, in particular, China.

6 The importance of inexpensive Chinese digital products such as smartphones, Wi-Fi routers, and network equipment in improving access in the developing world should not be underestimated.

7 For a discussion of Pinduoduo, see Chen et al. (2020).

8 Xinhua (2019) reports that 98% of rural Chinese villages have broadband access.

Despite advances in China and commercial agriculture, lack of Internet access is a continuing obstacle to the use of digital technologies in many rural areas. In such an environment, the smartphone provides mobile internet access and is the technology necessary for extending the benefits of digitalization to small holders[9] In Table 2, we compare the situation for small-holder farmers by drawing upon and extending the work by Friederici et al. (2020: 51) that explored African digital entrepreneurship. The experiences of African digital entrepreneurs illustrates the context within which small holders are expected to begin using smartphone apps.

TABLE. 2 | DIGITALIZATION VARIABLE COMPARISON RURAL AREAS IN DEVELOPED AND DEVELOPING NATIONS, 2021

Attribute (in relationship to farmers)	Developed Nation	Developing Nation (smallholder agriculture)
Telecommunications Quality	Good	Highly variable
Telecommunications Cost/Income	Low	High
Device usability	Excellent (variety of connected devices -- IoT)	Highly variable (feature phone or smartphone)
Technical support	Good to excellent	Generally very low
Skill Levels/	Payment for unbanked	Greater efficiency and speed
Digitalization	Varying but good	Very low
Access to Capital	Medium	Very low
Logistics Infrastructure	Excellent	Weak
Government involvement	Variable but good	Variable often very weak
Trust in institutions (online transactions, banks, etc.)	High	Low
Access to credit	High (crop insurance etc.)	Very low (and often at usurious rates)

Source: Adapted from Friederici et al., 2020

The obstacles to the adoption of digital technologies in developing countries are more than simply technical. For example, Friederici et al. (2020: 54) point out that the willingness of African consumers to adopt technologies was also conditioned by an understandable lack of trust in these digital connectivity systems; though given the accelerating smartphone adoption, trust likely has increased since 2017. Yet, smallholders suffer not only from their own lack of purchasing power, but also a lack of direct access to customers and thus must go through intermediaries that capture much of the value. The opportunities thus are large, but the obstacles to adoption and use that is equitable and meets the goals of increasing sustainability are equally large.

9 It is important not to completely underestimate the importance of mobile phones in rural settings as Jensen (2007) shows Keralan fishermen used cell phones to assist them in landing their fish in ports offering better prices for their fish.

5. RECENT MASSIVE INVESTMENT IN AGTECH STARTUPS

Over the past decade, enormous amounts of venture capital have been invested in the agrifood system (Graff et al. 2020). The goal of these venture capital-financed startups is to “disrupt” various agrifood systems through the use of digital technologies and the introduction of online platforms. A remarkable number of these smaller firms have sustainability as explicit goals in their charters. During the last decade, there has been a massive wave of VC investment globally in AgTech firms; many of which explicitly state that they aim to use their technology to disrupt agriculture (Graff et al. 2020). In 2018, $16.9 billion in VC was invested across the entire agrifood system from inputs to final home delivery (AgFunder 2019). In their study, Graff et al. (2020) found that of the 4,557 firms in their database, approximately 2,000 were in software and business, online and financial services-nearly all of these were based on digital technologies. While these startups were concentrated in the US, many were also located in Europe. Moreover, the population was truly global with 102 startups located in Kenya, Nigeria, South Africa and another 173 located in Latin America, with 88 in Brazil alone.

Digital technologies, because of their inherent plasticity and generative properties, have enabled this proliferation of entrants creating and offering new products and services. The variety of entrants leveraging the digital technologies to create enterprises in the agrifood system is remarkable. At the level of the farmer, the innovations include new cyber-physical systems, pure software programs, and apps that run upon and exchange data with existing platforms. There have been an enormous number of new firms trying to reorganize the agrifood value chain (for example, becoming new intermediaries between farmers and consumers). Other startups are developing applications that use scanners and QR codes to trace food through the value chain. The key is that, due to the generativity of digital technologies, new services can be developed. For example, “Connecting Food”, a French food-tech start-up, provides a smartphone application that allows consumers to scan a product’s QR code and have every node in the value chain, as far back as the farmer, displayed. The app draws upon the fact that at every node in a logistics chain, scanners track the product’s movement and this is all recorded in a database. The app simply taps into the cloud database through an API and this allows the chain to be displayed on the consumers’ smartphone.

The sheer variety of innovations being introduced is remarkable, as the cost of development has decreased and market access through the internet is easier. Creating apps has also been simplified, as software development kits are widely available for either the Apple iOS or, more important in the developing world, Google’s Android. Given the enormous number of software tools and “components” available through sites such as GitHub, much of the coding is simplified so that the developer can devote more time to securing adoption. Distribution through the app stores simplifies market entry.

The reduction in the costs of entrance and eased market access encourages increased innovation. As a result, one of the greatest obstacles to success is the sheer number and diversity of entrants. Competition is often between very similar products, all of which struggle for the same markets. There is a proliferation of apps mirroring the variety of crops and nodes in each value chain. To illustrate this proliferation in the agrifood area, a 2017 study of food waste-sharing platforms identified 91 globally. In the larger developed nations there were multiple platforms-none of which appeared to be tipping the market (Michelini 2018). Similarly, a 2019 study in Norway identified 10 online supermarkets and 44 online niche stores delivering food to consumers (Heidenstrøm and Hebrok 2021). A 2021 report by ISF-RAFLL found that there were at least 75 agricultural product and service marketplaces operating across Africa, South and Southeast Asia, and Latin America (ISF-RAFLL 2021: 4), but very few of them served more than 100,000 customers-in other words, they are not yet close to minimum scale. Because many of the agriculture platforms operating in Africa are subsidized by development agencies and foundations, they can survive even though they have limited usage (Krishnan et al. 2020).

This proliferation of entrants results in ferocious competition with few winners emerging thus far and almost certainly financial losses. For many of these new entrants, success will likely be measured in their adoption by farmers or consumers, with the ultimate result being that the firm and its product or service will be acquired by a larger incumbent firm or an established digital firm seeking to increase its presence in the agrifood system.

Platform longevity is of critical importance for farmers because if a farm optimizes its operations for a particular digital technology and the small firm supporting it fails, the farm would be left with an “orphan” software program that, almost certainly, would no longer be upgraded or supported. Another concern for farmers is that if they adopt the small firms’ technology, there is a possibility that their data will ultimately be transferred to yet another firm. With the farmer locked in, a new owner might change the terms and conditions of the relationship or have a different strategic relationship with the farmer.

In conclusion, there has been an enormous amount of entrepreneurship and VC investment in the agrifood industry globally. However, in 2021, it is difficult to identify many successful new entrants with the exception of Pinduoduo in China, those that were acquired by the incumbent agrifood industry firms, and a small number of startups that have listed on public markets. This apparent lack of success appears to be equally valid in developed and developing countries.

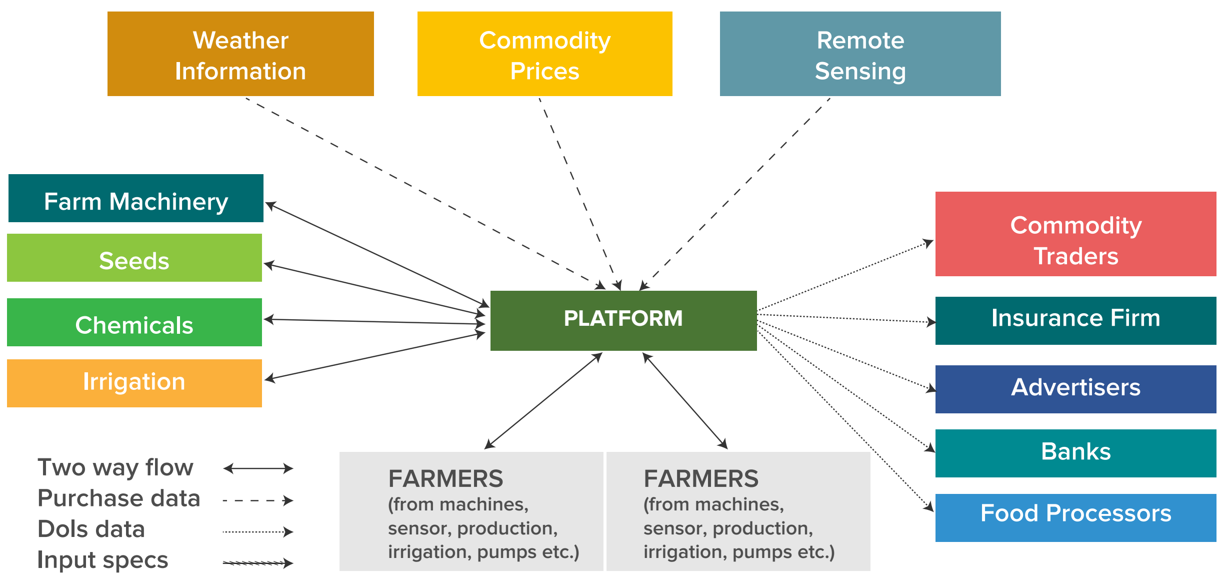
6. PLATFORMS AND DATA: OPPORTUNITIES AND PITFALLS

In previous work, Martin Kenney and John Zysman (2016; 2019; 2020; 2021) argued that the economy is being increasingly organized by online platforms. There is considerable debate regarding the definition of an online platform among those studying agriculture. For example, Runck et al. (2021: 3) adopts an expansive definition of a platform being a “group of technologies that are used as a base upon which other applications, processes or technologies are developed”. For this paper, we adopt a narrower definition namely that a platform is an online site that intermediates interactions between two or more different sides. This means that platforms perform a matchmaking function and for our discussion it is this function that is of greatest significance.

In a platform-organized market, the platform is the central intermediary that has panopticon-like situational awareness of all actions taken upon it. This confers extraordinary power upon the platform owner (for further discussion of platforms, see Cusumano et al. 2019; Parker et al. 2016). This is reinforced by the winner-take-all aspects of online platforms (Schilling 2002). The conundrum of platform-organized markets is that very often they provide remarkable efficiencies and, because they must share data with ecosystem members, provide new opportunities for the development of innovative applications or what Jonathan Zittrain (2008) termed “generativity.” For example, the Uber app was only possible because of the widespread adoption of smartphones and the fact that its app could integrate in Google Maps so that the customer can be easily located.

In agriculture, as in other industries, there was an initial phase in which, while computers were in use, they had little impact on everyday use. However, the inexorable progress of digitalization has now resulted in the introduction of increasingly “intelligent” machines and, this combined with the introduction of smartphones and their apps, is swelling the amount of data available and feasibility of using the cloud to combine that data with yet other data to create new services (Kenney et al. 2020). As a result of ubiquitous computing and connectivity, the farm level and the entire agrifood production and distribution system is being connected. The emergence of digital platforms in agriculture provides opportunities for entrepreneurship and innovation (Kenney et al. 2020; Nambisan 2017). Yet, at this time, these data streams are located in various silos, thereby hindering the efficiencies that could be achieved and new services that could be created were these data sources merged into a single platform (see Figure 2 for an ideal-typical, farm-centric illustration of the types of data that could be merged) in which the actors that could benefit and potentially innovate on or sell across such a platform.

FIG. 2 | IDEAL TYPICAL ILLUSTRATION OF THE TYPES OF DATA THAT COULD FLOW ACROSS AN AGRICULTURAL PLATFORM, 2020



Source: Kenney et al. 2020

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Enormous data sets accumulated by a central platform can be used to uncover new patterns that could result in recommendations that could optimize a variety of goals, of which one would be to increase sustainability without incurring greater costs. To provide an example, if in-field, geo- and time-tagged pictures of pests were uploaded by farmers to a central platform, it would be possible to analyze the progress of an infestation and direct treatments to, not only the current location, but also to block the projected path of spread (e.g., Michels et al. 2020). This is an example of low-cost collective action solutions that small holder farmers could implement. For poor farmers, the obstacles would be their capabilities, the cost of the smartphone (assuming the farmers did not have one) and the cost of data uploading. Yet the savings would be enormous, as governments could react more efficiently with informed and targeted eradication programs. If a government would provide free knock-off smartphones, subsidize training, and photo-uploading, and effectively prosecute the pest control measures, the social return could be enormous.[10]

The business opportunities in agriculture for introducing a platform to connect actors on the various platform sides are attractive. The following sections briefly consider the variety of actors that could develop a strategy to platformize agriculture (for further information, see Kenney et al. 2020 or Birner et al. 2021). As this report is farmer-centric, the analysis of these organizations does not include food delivery platforms or ghost kitchens-new business models that, as they evolve, may change the value chain in ways that impact farmers.

6.1. INCUMBENT AGRIFOOD INDUSTRY FIRMS

The incumbent agrifood industry firms have existing relationships with farmers that they seek to leverage to build a platform where farmers become ecosystem complementors. For these firms, this is, in part, a strategy of shifting their focus from simply selling a product to capturing a continuing flow of income from services attached to their product (Roy et al., 2009; Zysman et al., 2011). To accomplish this, their emphasis has shifted to capturing more data to both optimize operations, but also find new products and services based on an analysis of this data and other data they might have. For example, a seed company would get yield data from farmer's fields and combine this with climatic and social data and then analyze all of these in conjunction with what they know about the seed's genetics to breed a superior seed for particular micro-environments. In essence, the data derived from farmers would be combined with other data or repurposed to capture even greater value or sell insights from the data to other parties. While the preponderance of the profit will be derived from commercial agriculture in the developed world, improving data communications will provide opportunities to address the needs of small holders.

6.1.A. INCUMBENT AGRICULTURAL MACHINERY MANUFACTURERS

Today, nearly all farm machines, whether for the field or dairy, have significant information capture, processing and transmission capability that ranges from positioning or self-diagnostics to product or environmental sensors. For these firms and farmers, wireless bandwidth is an issue as rural areas in extensive agricultural regimes may have a low private return, so improved connectivity may require government subsidies. Smallholder agriculture that uses relatively hand tools or simple machines may not be of great interest to the farm equipment multinationals; though two-wheel machines are used, most do not appear to be digitized at this time (e.g., Van Loon et al. 2020). Caveats to this conclusion are important. First, while the equipment is not digitized, there are contractors that provide the use of the equipment and this may be done over mobile phones. Second, there is an ever increasing use of digital technologies and they will almost certainly come to this smaller equipment eventually. Finally, it may be possible to design smartphone apps that will assist in the use of this equipment.
John Deere was one of the first firms to begin offering platform-like services, as its equipment, especially the combine, became increasingly laden with digital technologies (Miles 2019). As today's combines and tractors move through fields, their sensors collect enormous amounts of data about the plants, soil, and the environment that is either transmitted directly to the cloud or stored to be uploaded when there is sufficient bandwidth. Ideally, the software provides data and analysis so the farmer can make a decision or, as is increasingly the case, the decision is directly communicated to the machine. One example of the machine's capabilities is its ability to predict parts failure-a vital service because unexpected breakdowns during harvesting are costly, as it may require a technician to be summoned while the machinery and the operator are idle.

For equipment makers, there will be significant difficulties in tipping the market toward their platform because farmers who are not using that specific brand of equipment have little incentive to use that brand's services. However, the efficiencies generated by the continuing digitalization seem to out-weigh concerns about data ownership, repair lock-ins, and the general increase in equipment prices. The increasing capability of the suite of digital tools embedded in the newest machinery makes 24/7 operation ever more feasible and even necessary to amortize the cost of new combines. For example, GPS guidance allows farmers to harvest day-and-night, a development that might contribute to increased concentration, as the more acres a farmer harvests the more rapidly the equipment can be amortized-a particularly important consideration as the constantly improving electronics speeds obsolescence.

6.1.B. INCUMBENT CHEMICAL AND SEED FIRMS

One of the key issues in agricultural sustainability is the use of agrochemicals and concern about the lack of genetic diversity in today's monoculture. Efficient seed planting and chemical application can decrease costs, increase yields, and minimize pollution. Because of this, chemical and seed firms see an opportunity to collect and analyze farmers' data and sell back to farmers the resulting recommendations, along with seeds and chemicals. If the yield and plant response data could be collected, then farmers would be conducting field "experiments" for the industry that could then monetize the knowledge gathered over millions of plantings.
In pursuit of these opportunities, in 2013 Monsanto (now merged with Bayer), one of the largest providers of chemicals and seeds, bought the Climate Corporation, a provider of weather prediction and insurance, for $1 billion as part of its service diversification strategy. To increase its functionality, the Climate Corporation platform has added more services, including SeedAdvisor, which recommends which seeds to plant, a service that identifies plant diseases, and a plant nutrition timing service (Bayer, Inc. 2019). In 2018, Monsanto announced that the Climate Corporation platform had 100,000 customers and would be opened to ecosystem complementors (Cosgrove 2018). By 2021 it had increased from 19 apps, at its inception, to 29. In principle, ecosystem complementors should increase the value of a platform, as they offer innovative services that increase user value. The road to profitability has not been easy. In 2016, Monsanto suggested that Climate Corporation would become profitable in 2020 (Plume 2016); however, there is little evidence that it has done so.

Agri-input firms have significant advantages in terms of recognition, financial resources, and the ability to package digital services with existing product lines. However, the difficulty is there is little reason for the various competitors to cooperate. More importantly, these firms have a fundamental conflict of interest-they sell chemicals and seeds -- and want to sell more. As is the case with all of these firms, the algorithms are proprietary and thus there are natural questions as to whose interest the algorithms are serving.[11] For small holders, technologies such as smartphone image recognition could provide the information necessary to reduce agricultural chemical usage-and this could be provided by either the public sector or private sector entities.

10 In China, broadband is provided by the state-owned telecommunications firms that cross-subsidize the coverage of rural areas and have a mandate to provide low-cost service society (Fan and Zhang 2021).

11 In 2020, a farmer charged the Climate Corporation with sharing his data with the startup Tillable, which aims to connect farmland owners to potential tenants. The Climate Corporation and Tillable had announced a "partnership," which was never explained. Nevertheless, the farmer received unsolicited offers to rent the land at a specific price, and he believed that the offer had been generated from Tillable's access to the data he shared by using the Climate Corporation. The FieldView application tracks the farmer's field from sowing to harvest and thus has data that enables estimation of the farmer's income and much else about the farm. This use of the data is entirely within the purview of the terms and conditions of the contract with the farmer (Janzen, 2020).

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6.1.C. COMMODITY-TRADING FIRMS

For commercial farmers everywhere, the ability to trade commodities is vital for profitability and already takes place online. Not surprisingly, farmers now use sophisticated software and trade either over their smartphones or personal computers. Twenty years ago, such trading platforms were only available to the global agricultural commodity traders such as Cargill and ADM, and various smaller grain traders, elevators, etc. (Bedford 2019). In October 2018, ADM and Cargill launched a grain marketing digital platform, Grainbridge, with tools that farmers could use. The platform is meant to allow farmers to consolidate their marketing and farm operations on a single platform.
This open platform is particularly interesting as it would appear to provide farmers with greater access. However, the intermediaries,ADM and Cargill, own and control the platform so they can operate it in their own interest. Were the platform to become dominant, it would provide its owners a monopoly position. Further, it would allow owners to disintermediate independent grain handling operations such as silos. This could allow farmers and the giant grain traders to reduce the local elevator to a commodity storage provider by disintermediating its importance in trading. Controlling trading platforms can be of vital importance and we return to this in the discussion of government-owned and operated platforms for smallholder agriculture.

6.2. EXISTING PLATFORM GIANTS

The US platform giants, with the exception of Amazon through its transformation of the distribution sections of the supply chain, are, at this time, only exploring the peripheries of the agrifood system. The situation in China is completely different as platform giants and buyers are now directly intermediating between farmers. In this section, we discuss not only the activities of Amazon, Google, Microsoft, and IBM, but perhaps the most significant examples thus far, which are the Chinese firms Pinduoduo (mentioned earlier) and Alibaba's Taobao. The importance of including the Chinese firms in this study is that Chinese firms have made important inroads into many developing countries in terms of infrastructure roll-out. This includes Huawei in mobile base stations, Chinese smartphone manufacturers selling low-cost Android phones globally, and the remarkable global success of Chinese mobile phone apps such as, Tiktok, Shein (clothing retailer), and Tencent games. Here, speculatively, one could imagine a firm such as Pinduoduo finding traction in middle-income countries connecting smallholder agriculture with urban consumers.
In terms of the US tech giants, there have been a number of agriculture-related initiatives, though it is too early to gauge their success. The advantages of these technology giants is that they have enormous resources and thus can tolerate significant losses for long periods on a pathway to ultimate profitability. The obvious drawbacks to these initiatives is that the agriculture-related projects are very small operations within the much larger firm.

The large firm with the most salient efforts to enter agriculture is IBM. In 2019, IBM announced that it was using its AI platform Watson to successfully predict the best date for activities, such as planting and harvesting (Dignan 2019). At the time, IBM was targeting large agribusiness firms and consultants that advise farmers (who presumably could pay for the service), rather than the farmers themselves (Miller 2019). More recently, it was announced that IBM Watson was partnering with a non-profit, Heifer International, a US-based NGO; CATIE, a Costa Rican-based regional research and teaching organization; and Honduran COPRANIL, a coffee cooperative and cocoa grower in Chocolate Halba. The plan was, to quote the press release, "to use predictive AI technology with geospatial, weather, environmental and IoT field data in a comprehensive dashboard tailored to a farmer's land. It delivers weather alerts and other information, such as optimal planting patterns and expected yields linked to market pricing" (Heifer International 2021). Then the beans will be tracked using IBM's blockchain technology that will provide supply-chain traceability, thereby presumably increasing consumer trust in the product. This and other projects suggest that IBM is investing significant resources in its efforts to supply software and cloud solution.

Microsoft introduced FarmBeats, an application on its Azure cloud computing that provides farmers with data, though at this point it is not commercialized (Wiggers 2019). In June 2020, Microsoft launched a fund to support agritech startups in India that would use FarmBeats as their backend (Ellis 2020). However, in 2021, the FarmBeats platform remains largely in beta and not yet economically viable.

Google, in many respects, also appears to be exploring its opportunities in agriculture, though this seems to have been confined to investment in VC-financed agritech startups, such as Farmers Business Network (Troitino 2018) and investment in research on agricultural technologies such as field robots (Okumura 2020). Given Google's capabilities, its ultimate goals are difficult to predict. For example, with the enormous reservoir of remote-sensing data it already has from Google Earth and Google Maps and analytical capability, it could certainly use this data as leverage to enter the agricultural space. Already, Google Android and Maps are integrated into an increasingly large percentage of the world's automobiles. It might be possible to extend this to farm equipment, thereby creating one standard to unite all the data being generated.

Of all of the tech giants, Amazon may be the most interesting, because of the range of its offerings. For example, Amazon Web Services, its cloud computing operation, appears to be developing services that are specific to the needs of the agrifood system (AgDaily 2019). In the grocery/food distribution industry, it already has a strong position, which only increased during the COVID-19 pandemic, due to the dramatic increase in online ordering from its Amazon Fresh and Whole Foods subsidiaries. It is important to recognize that it is becoming a major food retailer globally as Amazon Fresh has operations not only in the US but also in Western Europe, Japan, and India.

As Amazon has become an increasingly important distributor, retailer, and deliverer of groceries in a number of countries, it has developed relationships with other actors in the food value chain. In India, in some ways mirroring Pinduoduo's model in China, Amazon is establishing fresh produce collection centers that connect it directly with growers and Farmer Producer Organisations. These centers not only aid in procurement, but also can be used to recruit more suppliers to the Amazon supply chain (Kumar 2021). In addition to purchasing, Amazon has created a mobile app that provides alerts and addresses soil, pests, weather, disease and other crop-related queries. Further, the app includes machine-learning algorithms to detect defects in fruits and vegetables, so that farmers sort, grade, and pack produce for transport to AmazonFresh fulfillment centers (Rai 2021). This model was first introduced in India where supply chains were rudimentary, but, if successful, could be adopted in other developing countries. This initiative could improve supply chains and product quality in India and increase the prices that agricultural producers receive.

The final set of incumbent platforms impacting farmers and rural agricultural economies are Pinduoduo and Taobao (Alibaba)[12]. As mentioned earlier, both of these platforms are leveraging the government-built communications system, pervasive use of smartphones, smartphone-based payment systemS, newly developed sophisticated logistics system, and increasing interest in sustainably farmed, high-quality food among consumers to integrate farmers and rural producers, more generally, onto their platforms. Also, in contrast to most of such platforms in both the developed and developing countries, the Chinese ones appear to be successful and increase farmers' incomes (Li et al. 2021). The lessons from the Chinese success for other developing countries may be more about building the infrastructure upon which the platforms rest than on simply introducing a platform that cannot be used because the context is unprepared (Baisch and Scarfe 2020).

With the exception of Amazon, the US tech giants have shown only limited interest in the agricultural sector beyond offering cloud computing services and VC investment in agrifood system startups. Amazon, because of its increasingly significant grocery operations, is the firm one might expect to integrate further into the value chain. For example, it already offers white-label goods under the Amazon Pantry brand. Its Indian operations appear to have gone the furthest in exerting greater control over the supply chain for fruits and vegetables. What this overview shows is that Chinese platforms are by far the most advanced in developing an intermediary position between farmers and consumers. While there has been no economic analysis regarding whether the intermediation increases income for farmers, there is an assumption that it does.

6.3. COOPERATIVES

Farmers, as small business owners, are hesitant to adopt new technologies that invade their privacy or expose valuable data to outside parties that might benefit from it. Cooperatives, as they are owned by their members, might provide a collective action solution to this problem. The cooperative can operate as a trusted platform as its governance structure is composed of its members. For this reason, a cooperative can have different goals and thus price its services differently and, as important, return any efficiencies generated by establishing and operating a platform to the owners. The cooperative could collect reliable data from its members-and it would have collective power to sell the production data to other food system actors or analyze it itself. Further, if the platform data was made available to independent app makers, the platform could recoup some of the value created. Of course, if an app was particularly valuable, that functionality could be made available by the cooperative's platform[13].

12 On Taobao in agriculture, see Li (2020)

13 In other words, it would operate in the same way as any platform in the interest of its members.

Effectively, in the cooperative business model, farmers would provide their data to a platform in exchange for a share of the value generated from their data.
The goals of the cooperatives such as collective learning and sharing could be enhanced by the use of digital platforms and software (Como et al. 2016; Filippi 2014). As an example, InVivo, the enormous French cooperative of cooperatives, actively invests in digitization and the software that could form the basis for the data collection necessary to establish a platform. InVivo purchased Smag, a farm management software firm that owned Agreo and Atland, which are cloud-based agronomic data management software programs (InVivo 2016) that can be utilized from a farmer's PC or smartphone. In 2019, InVivo launched the platform Aladin.com that allows vendors to offer a wide variety of products and services, including those that are useful for alternative and sustainable products and practices. InVivo offers various kinds of software for precision farming that allow the analysis of field sensor data, seed-sowing densities, and soil fertility to inform variable rate fertilizer application.

In principle, it should be less risky for a farmer to provide data to a cooperative because even if it uses that data to increase income, it returns the income generated from the data to the farmer. In contrast to for-profit input suppliers that provide the platform as an adjunct to their main business line, cooperatives should have fewer conflicts of interest. For example, a cooperative has little incentive for recommending unnecessary repairs or chemical treatments to increase income. For farmers, ownership of software or data platforms used by members could only be sold or discontinued after the consent of its members, thereby limiting their risk.

In the multi-stakeholder examples discussed next, cooperatives are important actors because they can speak collectively for the target farmers. Cooperatives could provide a solution to the farmers' distrust of the platform and ensure that the interests of farmers are considered, thereby increasing adoption and ensuring that platform adoption did not result in exacerbated inequality-one of the key sustainable development goals.

6.4. MULTI-STAKEHOLDER PLATFORMS

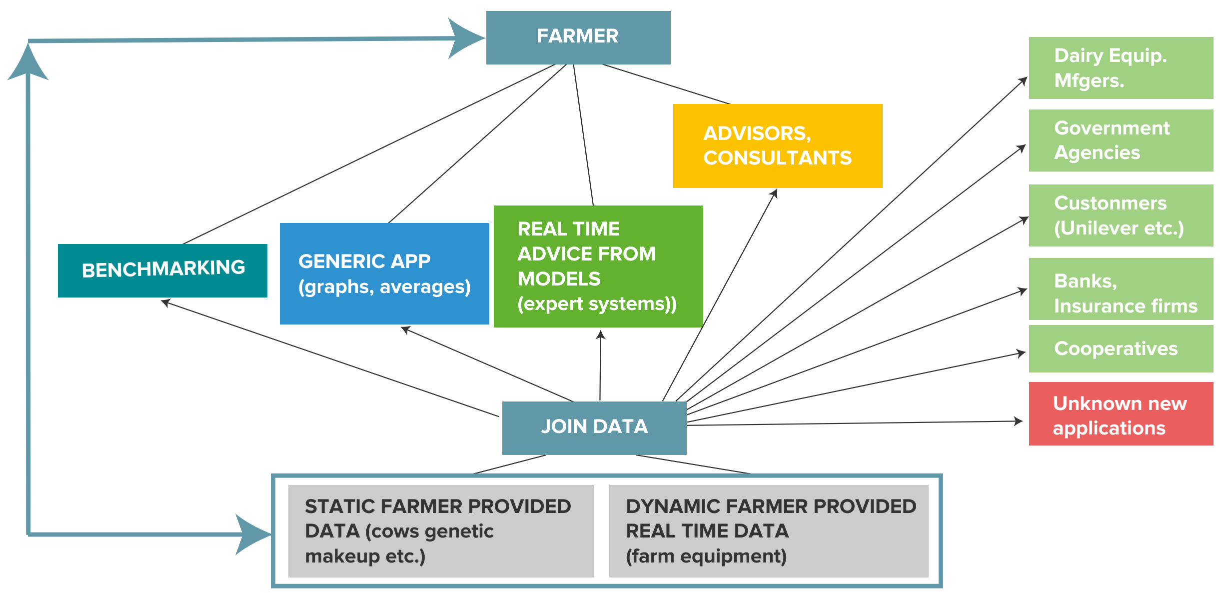
At the farm level, with the way current markets are organized, absent incentives, data sharing provides little benefit to those generating it and some risk of loss as the data could be used to, for example, assess the farm's income and deny credit. The data generated by farm equipment could have value to a number of actors, including the farm equipment maker who could use the data to improve future equipment that might be more expensive-a dynamic within which farmers would only be compensated indirectly for the value that their data made possible.
Given the value of the data and its non-excludable nature, if farmers provide data from their operations, it may be difficult for them to be directly compensated. For this reason, there has been significant experimentation with multi-stakeholder platforms, though even here there are difficulties because of the difficulty in providing incentives to all of the stakeholders.

The opportunities and difficulties in organizing effective economic arrangements to secure data sharing have led to experimentation with new business and organizational models. One model is to bring all of the stakeholders together into a consortium where the goal is to secure the benefits of a platform where data can be shared without losing control to a single self-interested platform owner.

One example of such a model is the "SmartDairy" project established in the Netherlands by a consortium that included the Dutch national research organization VNO, local universities, dairy cooperatives, dairy equipment suppliers, and, initially, seven dairy farms. The VNO created a software platform to which farmers could contribute their data, but then view all their relevant information with a single dashboard. The analytical software would analyze the uploaded data and, based on various algorithms, provide farmers with recommendations for the care and productivity of their individual cows.

In 2019, the project and its software was turned over to a newly formed clearinghouse platform, JoinData, which operated a data-broker platform business model (see Figure 3). As data brokers, farmers and firms could transfer data to each other because JoinData never owned or stored any data, acting merely as a clearinghouse. The software and platform have been successful at connecting approximately 15,000 Dutch dairies. Using this model, farmers can share their data with any interested parties: banks, insurance firms, production cooperatives, dairy machinery firms, and milk processors. In principle, the model should result in significantly improved recommendations and analysis. Like the startup Agrifind described earlier, SmartDairy operates as a clearinghouse, not a data repository.

FIG. 3 – DATA FLOW PATHWAYS FOR THE DUTCH SMARTDAIRY MULTI-STAKEHOLDER PROJECT, 2020



Source: adapted from v. d. Akker, 2020

Another European example is in Germany, where farmers are repurposing a variety of organizational models (the Ring model) developed for agricultural machinery-sharing to also provide data aggregation and analysis services. By acting together, farmers can collectively purchase high-cost machinery, such as combine-harvesters (Hastedt 2016) that, as it works the field, also collects geolocated data such as yield, moisture, and protein content that can be analyzed to provide individualized summaries and recommendations to farmers/customers (Giesler 2018). The addition of sensing and geolocation functions to its machines has increased the scope of the machinery-sharing organization from a collective-action solution for high capital-cost equipment to include valuable data generation. The data would not only have value to the farmers, but also to the equipment makers, commodity traders, government authorities such as the Ministry of Agriculture, and other entities that could combine the machinery data with yet other data sources. By accessing other data, such as weather data, the Ring organization could add further value to its offerings to farmers. The machinery's technical changes provide the opportunity for the Ring organization to evolve into a platform or a data intermediary that might also be able to offer yet other services from third-party vendors.

6.5. GOVERNMENTAL INVOLVEMENT

For the most part, digitalization and platformization has gone forward without significant direct government involvement or regulation. China is a significant exception because the telecommunications system's expansion was organized by the state-owned enterprises. In most of the rest of the world, telecommunications networks are privately owned and operated. With regard to online platforms, which scholars increasingly understand as being infrastructure (Plantin and Punathambekar 2019), there has been little discussion of nationalization or the provision of platforms by governments. In agriculture, the Nigerian government has experimented with the "platform-like" websites, but according to ISF-RAFLL (2021: 22) these are not platforms. Likely the private sector will continue to own and operate the platforms, but with increasing government regulation.

7. OBSTACLES TO SUSTAINABLE DIGITALIZATION AND PLATFORMIZATION

Despite the increasing mobile telecommunications coverage,decreasing cost, and increased ubiquity of inexpensive smartphones, farmers - especially those with limited means- may be unable to afford access, especially in terms of data downloading. An even larger question is whether the increasing digitalization favors larger farmers and, if it does, whether this is a desirable social outcome. As important, many farmers, while accepting and even embracing increasing digitalization, are concerned about issues such as data usage/ownership and, as agricultural equipment comes pre-equipped with ever more software, whether they will be able to repair their equipment.

As we have shown, those generating the data may or may not be able to extract and capture value from it. This creates asymmetric incentives between the individual generating the data and those that can extract value from it. For example, having direct access to a farm's production data could be of great value for a loan officer considering extending a loan to a farmer or calculating the probability that the loan will default. For a large investment bank considering investing in a food products firm, knowing the response of production to weather changes could be of enormous value, while knowing production at an individual farm would be of little value.

The adoption of connected digitized machines collecting various types of data is becoming standard as digital data is easily transmissible and costless. When the data exists and is easily available, it is far more difficult to resist demands for that data. So, while a dairy farmer may be reluctant to share such data with outside parties, it may be possible to compel the sharing. For example, a loan officer could demand access or deny a loan. Further, if the loan officer received such data, could they share it with a loan aggregator? Could the corporation making the loan aggregate the production data and share it with third-party data brokers or government officials? In each of these hypotheticals, the farmer would not be compensated for the further value derived from the data.

One of the fundamental characteristics of digitalization is that it increases transparency. From a systemic perspective, increased transparency can result in greater efficiency. For example, digitalizing a supply chain can lead to the elimination of unnecessary steps, such as distributors and intermediaries, thereby decreasing costs. Of course, those disintermediated no longer have a function. Digitalization can also be used to measure carbon footprints or, with proper devices, measure agricultural chemical application and runoff. All of these would contribute to meeting SDGs. However, for farmers, these could lead to them internalizing costs that they previously externalized into the environment-a development that they likely would not welcome, absent some sort of compensation mechanism.

8. POLICIES AND INVESTMENT OPPORTUNITIES FOR SUSTAINABLE DEVELOPMENT: SOME PARTICULARS

The advances in and opportunities created by digitalization and platformization in agriculture and rural areas are enormous. However, the context and impact of digital technologies are different in developed country commercial agriculture (whether in developed countries or in developing countries such as Argentina and Brazil) and small-holder agriculture in developing nations. The myriad differences in agriculture and its various value chains mean that investments and policy initiatives must be sensitive to context and be aware that safeguards aimed at ensuring equity must be designed-in prior to initiating an intervention.

The first consideration is the mobile telecommunications infrastructure and whether it provides sufficient connectivity in terms of data capacity and cost. In the developed nations, this has become a rural-urban digital divide. In developing countries, the capacity and cost problem is exacerbated by the fact that many smallholders cannot afford the smartphones or data plans necessary for using various applications. Development banks can address such problems by subsidizing or owning the telecommunications infrastructure and providing low cost service to farmers and entrepreneurs developing technology for agriculture. They could also buy inexpensive smartphones and provide them to farmers, if a standard model was diffused it would also simplify app provision, thereby encouraging entrepreneurship and innovation. Low-cost connectivity could be rapidly extended to farmers and, if owned by the government or quasi-governmental organizations, operated at low profit margins with the goal of providing connectivity. Governmental ownership or control is vital because, very often, subsidizing private owners can lead to monopolistic or oligopolistic outcomes that eventually lead to price increases after competitors are driven from the market, then allowing the owner(s) to increase their profit margins by raising prices to whatever level the market will bear -- and this would likely not be the socially optimal price.

To develop a robust e-commerce infrastructure, it is necessary to build an effective logistics infrastructure. In countries such as China, private firms have found it sufficiently profitable to build out their logistics infrastructure. For lower-income countries in parts of Africa and Latin America, this may be more difficult. In such cases, ensuring an effective postal service could remove this obstacle and ensure that the logistics system was not entirely privatized and susceptible to monopolization.

Digital payment systems already exist in many developing countries. Unfortunately, usage differs markedly from country-to-country. Development banks may have a role to play in ensuring that their operation is transparent and well-regulated, as they have an important role to play in the extension of the benefits of digitalization to rural populations and small holder farmers. Digital identity systems, such as the Aadhaar system in India may provide benefits, but could also have negative impacts (Chaudhuri 2021; Dattani 2021).

For farmers, intermediaries such as online platforms offer remarkable opportunities. If a platform organizes and captures a market, almost invariably, power flows to the platform because of some of the attributes of network industries.[14] Inherently, all actions on a platform are visible to the platform; as the market tips, eventually the platform is able to "see" the operation of such a large portion of the market that it becomes the panopticon. For example, as Amazon grew and captured ever larger portions of the US online market, it came to understand the flow of goods in the retail market in such a way that it had greater insight than the incumbent delivery firms, such as UPS, Fedex, and US Postal Service (a similar situation is developing for postal services globally).

14 By power, we mean the ability to structure the platform, decide on who can participate, subsidize certain participants and charge others, and, most importantly, decide how much of the value created due to efficiency and its control, it wishes to retain for itself.

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This allowed it to build out its competitive logistics systems with minimal amounts of risk. The building of its capabilities allowed it to offer ever more services to its users. Conversely, as the platform becomes more powerful, it has ever more points of leverage to compel previous non-users to use its services. To illustrate, in 2021 in the US, it is becoming increasingly difficult to purchase books and many other retail items outside Amazon. These developments have now become central concerns for regulators, not only in the EU, but rather among governments globally.[15] As public investors consider their digitalization and platform development strategies, it is important to understand that a successful platform will benefit from network effects and WTA outcomes. Such an outcome can provide enormous benefits, but building correct governance at the outset can ensure that inequities are mitigated.

Cooperatives play a vital role in many sectors of agriculture. But, as importantly, they could provide a collective action solution to the problem of data sharing. Development banks could be catalysts for solutions that increase overall efficiency, encourage innovation, and contribute to increased equity through working with existing cooperatives and the developing countries helping to form cooperatives around small-holder agriculture. As we saw in the case of SmartDairy, cooperatives can be one component of multi-stakeholder networks that organize various stakeholders by aligning the incentives of various participants.

In the developed countries, there has been a proliferation of angel- and VC-financed platforms aimed at linking farmers directly with consumers. Most of these are local and have social purposes such as assisting organic farmers or decreasing food miles. Unfortunately, nearly all of these suffer from precarious funding. National development banks should see these efforts as attempts to build infrastructure-as Amazon is building in these countries. Funding strategies that would create a common infrastructure, which could lower the costs for these disparate local startups so that they might better compete and ensure that national markets were protected and that the locally created value was not exported, could also contribute to the retention of wealth locally and the building of entrepreneurial local ecosystems. Here, the Chinese Taobao villages or the Pinduoduo program to teach farmers how to sell online could be examples. The alternative is that firms such as Amazon, eBay, and Etsy capture the value built by these platform-enabled connections and export it to the US West Coast.

Public investors can also play a role in ensuring that there are public alternatives to the digital and platform infrastructures that are becoming the way citizens communicate, consumers buy, and producers connect to consumers and other producers.

15 See the growing number of news reports on how Amazon pressures its sellers to use its Fulfillment by Amazon delivery services. The pressure is so strong that Amazon has become one of the largest delivery services in the US threatening to become larger than UPS or FedEx.

9. CONCLUSIONS

Barring unforeseen circumstances, agricultural sector digitalization is inexorable. For developed world farmers, equipment is increasingly equipped with sensors, communication, and computational capabilities that are directed by software. For smallholders in developing nations, the smartphone is the gateway device. Digitalization and platformization provides not only tools, but also resources and possibilities to generate innovations that can contribute to the attainment of many of the SDGs. Yet, digitalization and, particularly, platformization of agrifood systems and value chains also threaten to create greater inequality, disempower farmers, and transfer value from farmers to the platform owners.

The current trajectory is resulting in ever-growing flows of data that are not only analyzable in their own right, but also can be merged with yet other data to generate further value and even unanticipated future services. Some of these data flows will be owned and controlled by the farmer, but other data, such as that from remote sensing or for the operations of a piece of agricultural equipment, may be owned by off-farm parties. The farmers' data will have value to others, but the question remains: how will society prevent the farmer and farm workers from being sacrificed in pursuit of these goals? Will they be compensated for contributing their data to potential data repositories? Farmers, as small businesses, may be unwilling to provide their data to other actors absent some compensation mechanism. As is the case with consumers using digital platforms, legal and institutional protections might be necessary to ensure that incentives and protections are aligned to ensure the privacy and ethical uses of the data.

The key to using digitalization and platformization to support farmers and consumers must include the provision of an appropriate and fairly governed infrastructure to ensure that the value created is not entirely siphoned away by the most powerful actors in the value chain. Friederici et al. (2020) correctly conclude that for Africa, at this time, the use of the mobile internet by the average small-holder farmer is limited due to the costs of access. This is true but likely only temporary, as the GSM Association (2020) estimates that, by 2025, 475 million (up from 272 million in 2019) Africans will have access to the mobile internet, and, by implication, access in rural areas will also increase. If farmers that are producing export products for the global economy, especially, form collective action groups that could brand, direct-to-consumer platforms could provide increased income because developed world consumers will be willing to pay for environmentally superior cultivation practices. Here, national and international development banks could cooperate and achieve positive outcomes for the weakest parties in the supply chain.

The development banks could fund the development of platforms that could embody other social goals beyond establishing a monopoly so as to capture the bulk of the value created by the surrounding ecosystem(s). This is vital as platforms have become central infrastructures for economic and social interaction. While the private platform firms are implementing environmental sustainability into their operations, they do not have as their core concerns meeting SDGs or other social goals. As private entities, their motivation is to expand their businesses through acquisitions or the introduction of new services in their quest to grow[16]. Development banks, perhaps, by owning an inalienable "golden share" could support multi-stakeholder partnerships that ensure that the various stakeholders share in the value created, and, as important, ensure that no platform-side is exploited as it becomes dependent on the platform for survival. Such a guarantee would encourage contributions of data-flow that could make the entire system more efficient, thereby generating value for the entire ecosystem. Such an ownership structure would make it easier for the ecosystem participants to make the difficult choices necessary to meet the ambitious SDGs and contribute to increased social equity.

16 Because they are in industries that have winner-take-all dynamics, once they succeed in one sector, the only growth path is to expand to yet another sector or extend the scale and scope in that particular market. One example is the way in which Uber expanded from initially offering limousines to the far bigger, personal car market. From offering rides to people it extended its scope to offering food delivery.

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