NJAS - Wageningen Journal of Life Sciences 90–91 (2019) 100294

Contents lists available at ScienceDirect

NJAS - Wageningen Journal of Life Sciences

journal homepage: www.elsevier.com/locate/njas

Research paper

Looking through a responsible innovation lens at uneven engagements with digital farming

Kelly Bronson

School of Sociological and Anthropological Studies, Université d'Ottawa|University of Ottawa, 120 Université (FSS10006), Ottawa, ON, K1N 6N5, Canada

ARTICLE INFO

Keywords:
Big data
Digital farming
North America
Responsible research and innovation
Inequity
Diversity

ABSTRACT

This article extends social science research on big data and data platforms through a focus on agriculture, which has received relatively less attention than other sectors like health. In this paper, I use a responsible innovation framework to move attention to the social and ethical dimensions of big data "upstream," to decision-making in the very selection of agricultural data and the building of its infrastructures. I draw on original empirical material from qualitative interviews with North American designers and engineers to make visible and analyze the normative aspects of their technical decisions. Social actors shaping innovation hold a narrow set of values about good farming and good technology and their data selection choices privilege large-scale and commodity crop farmers by focusing on agronomic crop data and data mapping unusable to organic growers. Enabling engagement among a wide variety of food system actors, not just already powerful ones, and attending to a greater diversity of values would be essential to underpin a responsible digital agricultural transition.

1. Introduction

The future of farming is predicted to be "smart," using sophisticated sensors to collect big data and "intelligent machines" to mine them for information on how best to produce food. There has been a wealth of research revealing the impact of decisions made about big data use (Crawford and boyd, 2012), and decisions about who has access not only to these data but also to information about how data are used (see O'Neill, 2016). Critical attention to big data misuse is commonplace after events such as the 2018 Cambridge Analytica exposé. However, agricultural big data have received much less critical social science attention than data uses in other sectors (Carolan, 2016; c.f. Bronson and Knezevic, 2016; Carbonell, 2016; Driessen and Heutinck, 2015; Eastwood et al., 2017; Millar et al., 2010; Wolf and Wood, 1997). Moreover, social scientists have predominantly assessed the implications of the use or governance of digital agricultural tools, rather than the ways in which power and authority may be built right into their design. In this paper, I use a responsible innovation framework to move the moral compass further "upstream," to decision-making in the early selection of agricultural data and the building of its infrastructures. In particular, I interrogate what has predominantly been made sense of as an adoption issue beginning on the farm: a bifurcation of the market around digital innovations between large versus small, unconventional farms (see Paustian and Theuvsen, 2017).

Responsible research and innovation (RRI) calls for interrogations of the decisions taken by designers of technologies not just about what they are capable of doing but, normatively, about what the technologies ought to do and for whom (see Stilgoe et al., 2013). Guided by this RRI frame, I conducted interviews with 22 North American designers of agricultural big datasets and platforms to ask: What are the values—-about technologies, farming and food systems—held by these social actors and how do these appear to materialize in practice? This qualitative study suggests that design values and the decisions following from them are predominantly serving a few powerful food system actors and fostering divisions among farmers as well as among farmers and agribusinesses. In the end I make a case study of the open online platform *farmOS,* exploring its potential and limitations as a tool that works to overcome these technological inequities by introducing greater diversity into the digital agricultural socio-technical system.

2. Digital farming and its uneven adoption

While actors in food production have used computers and global positioning system technologies for decades, agriculture is currently undergoing a more fulsome digital transition. The "smart" farm uses sensors to collect data and intelligent machines to mine them and, ideally, to respond in real time to data-based advice (Wolfert et al., 2017). While this fully realized "farm 4.0" is not yet in existence (Weersink et al., 2018), all around the world computer software and hardware, sensors and algorithms are currently informing decision-

E-mail address: kronson@uottawa.ca.

https://doi.org/10.1016/j.njas.2019.03.001
Received 30 October 2018; Received in revised form 4 March 2019; Accepted 4 March 2019
Available online 08 April 2019

making on the farm (and indeed across supply chains) (Sundmaeker et al., 2016).

Digital tools currently in use in food production include remote and near sensors for collecting data. A well-developed space-based infrastructure of public and private satellites collect data relevant to food production (e.g., weather), and over half of operating farms in the United States collect data using "precision" machinery equipped with built-in sensors (Schimmelpfennig, 2016).[1] Indeed, every John Deere tractor sold today passively collects data on a host of farm-level variables (e.g., soil pH and moisture). After sensors embedded on farm equipment (or in some cases on drones) collect on-farm data, GPS tracking of field positions allows for the generation of maps displaying the spatial variability of the features under consideration (Scholten et al., 2013). Variable rate equipment can then be programmed to respond to the data-derived advice on when and where to seed, spray, or harvest. The use of monitoring and measuring farm-level data in order guide agricultural decision-making is called the "precision agriculture approach" (McBratney et al., 2005).

Adoption of precision agriculture has been uneven (Reichardt and Jurgens, 2009), even though industry, governments and funding agencies like the World Bank have gone to enormous effort (and expense) to persuade farmers of the environmental and economic benefits of precision agriculture. Indeed, industry actors have declared precision agriculture an altogether different way of doing business where the sale of data-generated positive outcomes has replaced the goal of maximizing profit via the sale of chemical and seed inputs. Tobias Menne, head of Bayer/Monsanto's Digital Farming, declared in a blog post for World Food Day in 2018:

> Before, selling more products meant more business for a company like Bayer; whereas in [the] future, the fewer products we sell the better, because we're selling outcome-based services. With sensor devices, we can learn a lot more about what is and is not helping crops and livestock and create a better way of doing things.

Some scholarship has verified that a precision approach can lead to judicious use of harmful or scarce farm inputs like chemicals and water (Adamchuck et al., 2010; Rossel and Bouma, 2016). Chemical inputs are not only damaging for ecosystems and human health, but they are also expensive. At the same time, a growing body of social science on this subject reveals that digital technologies may bring negative disruptions such as rearrangements of agricultural labour and expertise on farms that requires digital skills (Eastwood et al., 2017; Higgins et al., 2017; Holloway and Bear, 2017). Indeed, digitization could mean a shift in the very definition of farming with consequences for identity formation and the cultural fabric of agricultural communities (Carolan, 2016). Rose et al. (2018) found evidence that pressure to use emergent digital technologies is mismatched with the expectations of farmers about what farming is.

A number of survey studies gauging farmer adoption and opinion suggest that despite the promise of precision agriculture, not all farmers are enthusiastically engaging with digital innovations (Aubert et al., 2012; Batte and Arnholt, 2003; Bramley, 2009; Daberkow and McBride, 2003; Reichardt and Jurgens, 2009). In particular, several studies reveal that "intensive" (high technology, high input) farm management and large land size are positively correlated with the adoption of smart farming tools (Jensen et al., 2012; Lambert et al., 2014; Reichardt and Jurgens, 2009; Roberts et al., 2004) and the inverse is true. Said differently, the market for smart farming technologies is bifurcated between large, commodity farms whose managers are adopting these tools, and smaller-scale, unconventional growers whom are not adopting at equal rate.

Existing studies addressing this uneven adoption of precision agriculture are largely survey based. Dayton Lambert and colleagues focus on sequential adoption of digital agricultural tools and the influence of "farm characteristics" in their large-scale survey of cotton farmers across 12 U.S. states. They argue that the intensity of a farming system influences the cost structure and resources available for the purchase of innovations like sensors collecting farm data. Other large-scale surveys have found similar results, correlating farm size with precision agriculture adoption (Daberkow and McBride, 2003; Roberts et al., 2004; Reichardt and Jurgens, 2009). The high cost of many digital technologies is a known barrier to adoption among farmers (Reichardt and Jurgens, 2009), which costs disproportionately affect smaller, less intensive operations more vulnerable to financial risk. Similarly, surveys have established a link between crop type and precision agriculture adoption where cereal crops, typically grown on large and intensive farms, have been positively associated with adoption (Walton et al., 2010).

As Paustian and Theuvsen (2017) put it in their meta-review of this survey literature, most studies assume the farmer as the main driver of the adoption process. Many survey studies test discrete socio-demographic variables such as age and education in relation to adoption (Daberkow and McBride, 2003; Reichardt and Jurgens, 2009; Robertson et al., 2011). In their survey study, Roberts et al. (2004) found that PA adoption depended on the level of a farmer's knowledge about the costs and benefits of digital agricultural tools. Other studies have confirmed a link between digital skill and adoption (Daberkow and McBride, 2003).

There are a minority of studies on digital agricultural adoption which take a more "dynamic system perspective," one that accounts for how technical changes are embedded within complex structures of change and stability and at levels beyond the farm (Klerkx et al., 2012). Busse et al. (2014), reveal how a wider innovation system constitutes the framework that helps shape the ways by which farmers adopt digital animal monitoring technologies. Although they show the role of various actors along the value chain, they write that "the key part of innovations is supported by actors how [sic] are engaged in the crucial phases of R&D and production," not excluding the work of farmers. Similarly, Higgins et al. (2017) attempt to broaden views on farmer engagements with digital technologies by attending to the work of materials and materiality as constitutive elements in how farmers come to know and engage. They use interviews with Australian rice growers to reveal the "materially heterogeneous processes and implicit strategies that hold together and perform particular social and organisational arrangements." As with Busse et al. (2014); Higgins et al. (2017) find that corporate structuring of digital tools constrain rice growers' capacities to adopt precision agricultural, yet they show farmers developing alternative "ordering practices" to negotiate, work with and work around these constraints.

3. Theoretical framework and methods

Following from studies taking a broader approach to digital agricultural innovations, I inquire into the role of normatively-driven decision-making on the part of designers as it might play a role in the bifurcation of digital farming engagements. I use a responsible research and innovation framework to attend to the normative and power dimensions of innovations systems which is often neglected in the literature (c.f. Pigford et al., 2018; Schlaile et al., 2017).

3.1. Framework

The RRI theoretical framework broadly aims to address those aspects of scientific and technological research and design related to

[1] A comprehensive adoption study has yet to be completed in Canada, though Agriculture and Agri-Food Canada (AAFC) did contract one survey on adoption in 2015, completed by agricultural engineer Dan Steele, which showed less adoption relative to the U.S. A colleague (Dr. Maaz Gardezi) and I are currently working with AAFC on developing a protocol for a comprehensive "socio-ecological" analysis of adoption across Canada.

social and ethical dimensions, and it does so in order to *a priori* anticipate (and thereby potentially mitigate) socio-ethical harms (Stilgoe et al., 2013). RRI scholars advance the position that technologies and society are mutually shaped; innovation is equally about people as it is about products, processes and technical systems (Guston, 2014, p. 2). Following from this, norms and values are not something that can be taken out of the production of technologies. As such, they ought to be made explicit and deliberated upon as a way of matching them to societal values, preferences and choices. Said differently, RRI begins from the premise that the mechanism for responsibility is engagement with values-based questions "upstream"—or early in the innovation process.

When it comes to governance decisions about technologies, acknowledging the vital role values in the shaping of innovations is complex work, yet there is growing enthusiasm for doing so (Guston, 2014; Owen et al., 2013; Wiek et al., 2016). RRI has come to the fore in connection with a variety of technologies which present potentially high stakes and high uncertainty (Funtowicz and Ravetz, 1993). There has been very little attention to smart farming through an RRI lens (Rose and Chilvers, 2018; except Eastwood et al., 2017), despite a wealth of research in other sectors revealing the clear implications of digital tools, big data and artificial intelligence (Crawford and boyd, 2012). As with social media, smart farming raises questions about how to protect user privacy, equitably distribute power and control and mitigate negative disruptions to social and cultural relations (Hellström, 2003).

While privacy and access and equity can be aided by proper management of digital tools, importantly, in this paper I use RRI as a rubric to focus on upstream processes. Specifically, I a) interrogate the values of designers and b) assess their material practice for its capacity to incorporate a diversity of societal values and needs (Stilgoe et al., 2013). I ask into the values about technologies, farming and food systems that are being encoded into digital agricultural innovations in North America. I am attuned to the ways in which designers' values might exacerbate or disrupt relationships of power in the food system among conventional and unconventional farmers, as well as between farmers and agribusinesses. This problematization is animated by a history of food studies scholarship which has revealed power imbalances in the global food system (deSchutter, 2015; Friedmann, 2005; Lang and Heasman, 2004), specifically between smaller landholders or peasant farmers and corporate entities. These critiques have suggested that inequities are inseparable from the industrial model of food production, central to which are science and technology. Scholars have tracked the massive disparities between farm-level income and the profits of large agribusinesses (see Clapp, 2012). Moreover, recent high-level empirical reporting (e.g. IPES, 2016) reveals the negative environmental and social consequences of such inequities and imbalances for food security and sustainability.

3.2. Methods

I address my aim of interrogating design values and practice through a qualitative research method. I conducted 22 unstructured qualitative interviews with designers of smart farming technologies working in the private (14) and public sectors (8) in Canada and the US. I asked interviewees open-ended questions about their practice, motivations and goals in relation to agriculture and technology. The designers I interviewed are scientists and engineers of various specialization including computer scientists, computational biologists, statisticians, geo-position specialists and agricultural engineers. They are spread almost evenly from across North America and were all recruited via purposive sampling that was "snowballed" from a few initial participants selected from existing networks. I conducted interviews, predominantly over the phone, lasting anywhere from 60 min to three hours. The interviews were conducted between January 2016 and June 2018. I then transcribed recordings of the interviews and coded them inductively, organizing key themes using the software program *NVivo Pro 11*. All interviewees were rendered anonymous in the paper unless they asked not to be.

4. Results and discussion: inequity in the design of digital farming innovations

My qualitative research sheds light on how the bifurcation in the market for smart farming technologies may not simply be an adoption issue beginning on the farm (and with farmers); rather, it at least partly results from partial and normatively motivated design decisions which are helping to produce digital farming "haves" and "have-nots." Similar to research on the "digital divide" showing how information technologies have aggravated social exclusions and divisions (see Gorski, 2003; Wong et al., 2009), not all farmers are equally advantaged via digital tools. Specifically, those designers I interviewed are motivated to solve problems facing commodity producers, and farmers are conceived as rational agents intended on maximizing economic return. The tools being made are subsequently of little use to farmers working outside of the dominant industrial model. As such, the results of my interviews reveal that decisions about data collection and the building of infrastructures reproduce historic relationships of power by serving already powerful food system actors and the current dominant food system model.

4.1. Farming as business

Wade Barnes is the CEO of a Canadian agribusiness leader in digital agriculture called Farmers Edge. Barnes describes that he has always been guided by the intuition that "good farming needed good information." Like every corporate actor I interviewed, Barnes's sense of "good farming" is deeply conditioned by upbringing—in his case, a childhood spent farming on a medium sized grain farm operation in the mid-west. According to my interviewees, a successful farm is a business, managing financial risk and thereby maintaining the economic viability of agricultural labour and indeed the wider rural communities anchored by such labour. Almost all of the designers I spoke with used language that indicated they assume, first and foremost, that the farmer is a rational individual whose primary goal is to maximize economic return. 'Jim' from another prominent agribusiness told me that his "motivation" is to use "data-driven" farming "to help the agricultural sector by helping farmers cut costs and boost productivity." The lead of "precision analytics" at a Canadian-based agribusiness, 'Charles' revealed how he is hoping to use data-based decisions to "minimize yield variability" ultimately in service of making Canada more "competitive." "The issue," he put it, "is that our area is under a strain for yield. … it tends to be the lowest yield in the area, in all of North America. We're uncompetitive …."

The majority of commercially developed big agricultural data and data platforms are useful to farms like the one on which Barnes spent his childhood. As with genetically engineered seed systems (Welsh and Glenna, 2006), corporate designers are focussing data selection only on major agronomic commodity crops. Because of their relative value, agronomic crops such as corn, canola, or soy are typically planted on extremely large acreages, and for a host of reasons (land cost, environmental variation) there is an east-west split fragmenting land size across North America and, subsequently, the market for agricultural machinery. In western Canada and the U.S., the emphasis is typically on large farm commodity cropping, with whole regions now dominated by wheat, corn, or canola. The average farm in Saskatchewan, Canada, is 1700 acres, versus 750 acres in Ontario, Canada, or 261 acres in Nova Scotia (Statistics Canada, 2016). In addition, in the mid-west there is a tendency toward industrialism, or managing the farm like a business. Variations in land size and strategy map onto differences in technological needs for farm machinery. Expensive pieces of equipment, such as the newest tractors and combines, best suit large holdings of over 1000 acres, where turnaround at the edges of fields is easier, where there is a lack of variation of topography, and where there is more capital available for investment in equipment than in smaller farms.

It appears that data scientists and engineers working in agribusinesses are working within rather than disrupting historic patterns of variation in land size and strategy. The micro-feeds of data used to build or teach the commercial data platforms and algorithms come from sensing (precision) machinery, or "plug-in" telematic sensors that work on machinery; these are very expensive technologies only used by large-scale industrial farms. Furthermore, in order to benefit from the advice generated by the commercial big data platforms, one also needs machinery allowing for "variable rate" application of inputs like chemical pesticides. Otherwise, knowing that a particular area of one's farm needs a particular application load would be of little use.

Like historic agricultural technologies—from Jethro Tull's seed drill to genetically modified organisms—commercial data infrastructures actually perpetuate as much as they result from the bifurcation of food production practices (Tanahill, 1973). Standardizing the environment by turning to mono-cropping was historically necessary for large agricultural machinery, and was as much a precondition as a product of industrial farming. Similarly, the maps created within those big data platforms developed by industry are made meaningful only if one adheres to a rigid conventional farming strategy of seeding in neat rows separated by areas of soil free of weeds. One designer I interviewed boasted about the power of their mapping platform to display "unprofitable" field areas with "weaker" plant density. Designers talked in interviews with pride about how density maps indicate, using colour variability, those areas that might require "attention" (notably, increased fertilizer) in order to increase growth. Such environmental mapping will fail to help an organic farmer, for instance, whose seedlings may be surrounded by plastic or mulch weed cover.

4.2. Agribusiness Advantage

Almost every one of the data scientists and designers I interviewed explained to me that they prize tightly controlled data collection and storage as essential to securing user privacy and, for technical reasons, to ensuring data reliability. Wade Barnes is known for advertising Farmers Edge as a "leader in *independent* data management" (YouTube, Farmers Edge Our Story, emphasis mine) because the company collects only those data which their in-house engineers, agronomists and data scientists believe necessary for uncovering information most useful for particular farms. Data are collected from across Farmers Edge consumers using a private system of weather stations and proprietary "telematic devices," or plug in sensors installed on farm machinery. The company also collects remote environmental data from a private constellation of satellites (via a partnership with Planet Labs). "Today," Wade says, "we are in the business of *decision* ag… right now in precision agriculture there are lots of people collecting data but fewer people using good data to make smart decisions on the farm."

These technological values are wrapped up in values about farming as business. Many interviewees explained to me that farmers are happy to trade restricted usage for the expertise required to generate insights from data. The dominant conception of the farmer circulating among corporate designers is of busy people whose primarily responsibility is managing a team of specialists, which now includes for-hire data scientists. One data scientist put it this way: "You know you can have data, ten datasets, that really don't seem to have much value in and of themselves but you integrate them in a novel way and you can have a billion dollar business."

The concentration of data expertise and prowess has the potential to further inequity between farmers and agribusinesses. Commercially collected agricultural data are predominantly housed in the cloud, on servers owned or controlled by input or machinery companies. We know that these farm-level data are used to "teach" predictive algorithms, but the full extent of their use is obfuscated from farmers and the general public, as the corporation's own privacy and access agreements govern their use. My analysis of these agreements shows that none specify the particular allowable uses of agricultural data by corporations or third parties. We can infer that the collected data are used for corporate gain, such as profile development for targeted marketing. Isabelle Carbonell suggests that such data uses, give corporations "a privileged position with unique insights into what farmers are doing around the clock, on a field-by-field, crop-by-crop basis into what is currently a third or more of the US farmland" (Carbonell, 2016, p. 2; see also ETC Group, 2018).

4.3. FarmOS

While commercial design decisions currently support a technological trajectory for digital agriculture that furthers the dominant, industrial model, amended for reduced inputs, there is another model for its realization founded on a different set of values. There are activist groups of farmers, scientists and engineers working in Canada and the U.S. on technologies that they feel will support diverse farming operations via a more open design framework—one which engages with a variety of end users and which aims to seek redress for historic food system exclusions.

FarmOS is an open-source agricultural data platform supported by a loosely organized and transient group self-describing as "non-hierarchical." The membership in this innovation community includes individual public-sector researchers from government (the U.S. Department of Agriculture, Extension and Conservation) and academia (e.g., Tufts), and a variety of farmers, most of whom are unconventional (e.g., market gardeners and no-till planters). The developers of *farmOS* are consciously attempting to fill the blind spots in agricultural research, and directing their product at "alternative" or "unconventional" producers, such as market gardeners.

One developer working on *farmOS* said that the main challenge when designing a platform for unconventional farmers is to "represent enough aspects of farming in a generalized way and to include information from cheap sensors and public data." Diversity and accessibility are central values for this community and constitute what one designer called its "development methodology." This method guides everyone's work: All of the code is visible and freely available, anyone can install the platform or host the system, and anyone can contribute by writing code and developing novel features. Moreover, *farmOS* is being developed in close connection with the farmers using it, not just because some (though not many) of those farmers are also writing code, but because the data scientists explicitly rely on user feedback. One female computer scientist called 'Jane' whom is working on the platform put it this way:

> What we care about is this idea of shared common, whether it's things like shared information, shared resources or community building. There is a sense of collective action. There is a sense of responsibility, not just to yourself but the environment that you're working in and tools that we build are responsive to needs. … I hear farmers talk about … or like in my grad work I did a lot of qualitative research trying to learn from farmers what that goal is, what they care about, what they're interested in doing in sustainable agriculture. I would hear their stories and learn more about their practice.

One activist leader 'Don' described the design approach, stating, "Along with the software, we are also trying to build a *community* around the software" (emphasis mine). They continued:

> The goal is to create a diverse knowledge base that individuals can build upon. The reason its open source is so we can build a global community around it. To serve as a platform for farmers but also researchers and service providers. Data and knowledge ownership is also an important piece of this … a lot of the commercial software systems don't give access or control over farm-level environmental

data. You sign that away.

Thus far, guided by these values and method, a variety of contributors have shaped the *farmOS* platform with interesting distinctions from the commercially developed tools. There is field mapping conducted using open satellite and other public data, such as U.S. Department of Agriculture soil data. Yet *farmOS* allows for the collection of any type of farm data by any means. For instance, some farmers may weigh their grain yield (bag by bag) on a scale, pencil the results on paper/clipboard, and wait until winter to digitize and upload the data to *farmOS* (as a KML file). There are almost as many data collection methods currently surrounding *farmOS* as there are participants. One small-scale farmer with minimal chemical input in Norway used a fitness self-tracker to collect GPS data for record-keeping on those field locations where they had sprayed. *FarmOS* allows for logging any such "event" within the platform, and it is up to the individual farmer to decide what might be a meaningful event, given their farming practice (s) and management goals. Events can be weather or data, the application of inputs like chemicals or water, or even the process of weeding by tractor or by hand. Farmers can also log their "assets" and, again, it is up to them to decide what constitutes an asset. To those farmers using *farmOS*, assets appear to be animals, plantings (crops), equipment, labourers, compost piles, mushroom or soil substrate, and maple stands or groves within a farm field, among others.

With its commitment to open data and a wide variety of collection methods, the design approach behind *farmOS* arguably fulfills some of the requirements of responsible research and innovation (see Eastwood et al., 2017), and may drive a more equitable realization of the smart farming transition; However, it is currently marginalized compared with private sector research. Historically, for-profit scientists have not necessarily explored the problems experienced on smaller farms which represent a fraction of their market for commercial innovations and this remains true for digital agriculture. One agronomic economist named 'Chris' interviewed for this study explained, "Of course industry is interested [in designing technologies for] large farmers, they are the ones with money to pay." Another industry representative 'Ema' put it this way: "There's not that much regard for smaller family farms… it's not that [big businesses] don't care, it's that they don't know they should care. Smaller farmers aren't as profitable…"

The inequity in engagements with the digital transition in agriculture although unsurprising from a business perspective, becomes exaggerated when designers and scientists working in the private sector (compared with those working on tools like *farmOS*) are more influential with government and funding agencies than those working outside of industry. My interviews indicate taht government decision-makers are also failing to engage with the principles of responsible research and innovation in their decisions about which smart farming innovations to support. This finding confirms previous studies showing government research and extension efforts devoting more money to the development of technologies meant to solve the problems of large-scale commodity farmers (e.g. Wilson, 2001) around which there is momentum. In my participation at conventions and farm trade shows since 2016, I have witnessed a significant public sector promotion engine—which includes professional association communication and articles in academic journals (notably *Precision Agriculture*)—behind this socio-technical trajectory. Somewhat paradoxically, the centralization of data prowess in the hands of corporations may prevent data access and knowledge-building in the public domain. One Canadian federal data scientist named 'Andy' put it this way:

> There is [sic] sensors on satellites that are run by various space agencies within the governments: American, Canadian, Japanese, oh you know European. … We have access through open data policies to a lot of these instruments, so we download, acquire, and download tools to process these data and we get a lot of the data for free. Now some of the data you have to pay for and with government we don't have a lot of money to do these things, so we have to be opportunistic in the sense that we use the data that's free, open, and available to us that's going to allow us to produce information to the government agriculture sector as a whole.

5. Conclusion: achieving a responsible smart farming revolution

This study has supported the findings from other studies on the digital agriculture ecosystem: that normative directions for agriculture can play out at a multitude of levels beyond the farm (Schlaile et al., 2017). Decisions made by scientists and designers can impact the directions which food systems, under innovation-led social change, take. And dominant directions have momentum and more easily "lock-in" or reproduce power dynamics, among else, within an innovation ecosystem (Stirling, 2011; Ingram, 2018; Schlaile et al., 2017; Touzard et al., 2015). Using a responsible research and innovation (RRI) lens in this study allowed for reflection on the normative aspects of digital agriculture at the design stage which, at least in North America, appears to be feeding into what has predominantly been flagged as uneven adoption. Social actors working in private and public contexts to shape these innovations hold a narrow set of values about good farmer, farming and good technology and their data practices privilege large-scale and commodity crop farmers. This study contributes to a history of scholarship in science studies on the "politics of technology" (Winner, 1986), and also to work in innovation studies calling for attention to power and negotiation at the level of the innovation community as a means to sustainability (Avelino and Wittmayer, 2015).

This study's findings suggest the need for an RRI rubric to guide the digital agricultural transition, ensuring that innovations are designed to deliver benefits such as improved productivity and/or eco-efficiency that can be widely shared. David Christian Rose and Jason Chilvers recently (2018) called for such an RRI rubric to foster the goals of reflexivity and inclusion in the context of digital agriculture. Because a concrete socio-technical system has not yet solidified around digital farming, there is time to carefully shape digital innovations and their infrastructures for a diversity of food system actors. Fostering inclusion and diversity in many areas, including farm strategies and sizes, has been established as key to meeting food system and environmental crises (see IPES, 2016). However, this study suggests that an equitably realized digital farming transition demands a high level of *social* rather than simply technical innovation among corporations, public sector scientists and engineers, government funding agencies, professional associations, activists and academics who all have a crucial role to play.

Here are three concrete suggestions for possible incorporation into such an RRI rubric. One, if the centralization of data collection and management just like GMOs enlists innovations as "vehicles of corporate supremacy" (McMichael, 2009, 140) then bold governance decisions could be taken to regulate the very collection of personal (in this case farm-level) data in the interests of the many instead of the few (e.g. General Data Protection Regulation, 2018). Two, if tight corporate control over agricultural data is as much a manifestation of historic patterns of consolidation among agribusinesses (see also Fraser, 2018) as it feeds into these patterns of corporate power in the food system, then legal measures could be taken to prevent uncompetitive markets which enable a level of interoperability among agribusinesses demanding streamlined and standardized data systems. Three, further academic work could be done to engage designers and engineers and get them to reflect on the normative aspects and purposes of digital farming innovations as they are taking shape: Why are these data being collected and not others? Who exactly stands to benefit from this specific research question? What kinds of historic injustice might this engineering decision reproduce? To repeat a phrase used in my introduction, we need to move the moral compass further upstream, to press for and initiate as well as to regulate a more equitable distribution of both agricultural data and data-gathering mechanisms.

Funding

This work was supported by the Social Sciences and Humanities Research Council of Canada via both a Canada Research Chair (II) in Science & Society and also by an Insight Development Grant (#231078-190599-2001).

References

Adamchuck, S., Viacheslav, I., Gebbers, R., 2010. Precision agriculture and food security. Science 327, 828–831.

Aubert, B., Schroeder, A., Grimaudo, J., 2012. IT as enabler of sustainable farming: an empirical analysis of farmers' adoption decision of precision agriculture technology. Decis. Support Syst. 54, 510–520.

Avelino, F., Wittmayer, J.M., 2015. Shifting power relations in sustainability transitions: a multi-actor perspective. J. Environ. Policy Plan. 1–22.

Batte, M., Arnholt, M., 2003. Precision farming adoption and use in Ohio: case studies of six leading edge adopters. Comput. Electron. Agric. 38, 125–139.

Bramley, R., 2009. Lessons from nearly 20 years of precision agriculture research, development and adoption as a guide to its appropriate applications. Crop Pasture Sci. 60, 197–217.

Bronson, K., Knezevic, I., 2016. Big data in food and agriculture. Big Data Soc. 3, 1–5.

Busse, M., Doernberg, A., Siebert, R., Kuntosch, A., Schwerdtner, W., König, B., et al., 2014. Innovation mechanisms in German precision farming. Precis. Agric. 15, 403426.

Carbonell, I., 2016. The ethics of big data in big agriculture. Internet Policy Rev. 5, 1–13.

Carolan, M., 2016. Publicising food: big data, precision agriculture, and co- experimental techniques of addition. Sociol. Ruralis 57, 135–155.

Clapp, J., 2012. Food. Polity Press, Cambridge, UK.

Crawford, Kate, boyd, d., 2012. Critical questions for big data. Inf. Commun. Soc. 15, 662–679.

Daberkow, S., McBride, W., 2003. Farm and operator characteristics affecting the awareness and adoption of precision agriculture technologies in the US. Precis. Agric. 4, 163–177.

DeSchutter, Olivier, 2015. Don't let food be the problem: producing too much food is what starves the planet. Financial Post(July/August) (Accessed August 2018). http://foreignpolicy.com/2015/07/20/starving-for-answers-food-water-united-nations/.

Driessen, Clemens, Heutinck, Leonie, 2015. Cows desiring to be milked? Milking robots and the co-evolution of ethics and technology on dutch dairy farms. Agric. Hum. Values 32, 3–20.

Eastwood, C., Klerkx, L., Ayre, M., Dela Rue, B., 2017. Managing socio-ethical challenges in the development of smart farming: from a fragmented to a comprehensive approach for responsible research and innovation. J. Environ. Ethics 1–28.

ETC Group, 2018. Year End Status of the Agribusiness Mega-mergers, Software v. Hardware, Deere and Co. Is Becoming Monsanto in a Box. Annual Report, December 2016. (Accessed September 2018). http://www.etcgroup.org/content/deere-co-becoming-monsanto-box.

Fraser, A., 2018. Land grab/data grab: precision agriculture and its new horizons. J. Peasant Stud. Published Online January 10https://www.tandfonline.com/doi/full/10.1080/03066150.2017.1415887(Accessed October 2018).

Friedmann, H., 2005. From colonialism to green capitalism: social movements and the emergence of food regimes. In: In: Buttel, F.H., McMichael, P. (Eds.), New Directions in the Sociology of Global Development. Research in Rural Sociology and Development, vol. 11. Elsevier, Oxford, pp. 229–267.

Gorski, P., 2003. Privilege and repression in the digital era: rethinking the sociopolitics of the digital divide. Race Gender Class J. 10, 145–176.

Guston, D., 2014. Giving content to responsible innovation. J. Responsible Innov. 1, 251–253.

Hellström, T., 2003. Systemic innovation and risk: technology assessment and the challenge of responsible innovation. Technol. Soc. 25, 369–384.

Higgins, V., Bryant, M., Howell, A., Battersby, J., 2017. 'Ordering adoption': materiality, knowledge and farmer engagement with precision agriculture technologies. J. Rural Stud. 55, 193–202.

Holloway, L., Bear, C., 2017. Bovine and human becomings in histories of dairy technology: robotic milking systems and remaking animal and human subjectivity. Br. J. Hist. Sci. Themes 2, 215–234.

Ingram, J., 2018. Agricultural transition: niche and regime knowledge systems' boundary dynamics. Environ. Innov. Soc. Transit. 26, 117–135.

IPES, 2016. or International Panel of Experts on Sustainable Food Systems. Report to the United Nations, June. . Online at http://www.ipes-food.org/images/Reports/UniformityToDiversity_FullReport.pdf (Accessed February 2019).

Jensen, H., Jacobsen, L., Pedersen, S., Tavella, E., 2012. Socioeconomic impact of widespread adoption of precision farming and controlled traffic systems in Denmark. Precis. Agric. 13, 661–677.

Klerkx, L., Van Mierlo, B., Leeuwis, C., 2012. Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions. In: Darnhofer, Gibbon, D., Dedieu, B. (Eds.), Farming Systems Research into the 21st Century. Springer, The New Dynamic, pp. 457–483.

Lambert, D., English, B., Harper, D., Larkin, S., Larson, J., Mooney, D., et al., 2014. Adoption and frequency of precision soil testing in cotton production. J. Agric. Resour. Econ. 39, 106–123.

Lang, T., Heasman, M., 2004. Food wars, the global battle for mouths. Minds and Markets. Routledge, London, UK.

McBratney, A., Whelan, B., Ancev, T., Bouma, J., 2005. Future directions of precision agriculture. Precis. Agric. 6, 7–23.

McMichael, P., 2009. A food regime genealogy. J. Peasant Stud. 36, 139–169.

Millar, B., Arkesteijn, V., Leeuwis, C., 2010. Enhancing the reflexivity of system innovation projects with system analyses. Am. J. Eval. 31, 143–161.

O'Neill, K., 2016. Weapons of Math Destruction, How Big Data Increases Inequality and Threatens Democracy. Crown Books, New York, NY.

Owen, R., Stilgoe, J., Gorman, M., Fisher, E., Guston, D., 2013. A framework for responsible innovation. Responsible Innovation. John Wiley and Sons, London, UK pp 270-50.

Paustian, M., Theuvsen, L., 2017. Adoption of precision agriculture technologies by Germancrop farmers. Precis. Agric. 18 (5), 701–716.

Pigford, A., Hickey, G., Klerkx, L., 2018. Beyond agricultural innovation systems? Exploring an agricultural innovation ecosystems approach for niche design and development in sustainability transitions. Agric. Syst. 164, 116–121.

Reichardt, M., Jurgens, C., 2009. Adoption and future perspective of precision farming in Germany: results of several surveys among different agricultural target groups. Precis. Agric. 10, 73–94.

Roberts, R., English, B., Larson, J., Cochran, R., 2004. Adoption of site-specific information and variable-rate technologies in cotton precision farming. J. Agric. Appl. Econ. 36, 143–158.

Rose, D.C., Chilvers, J., 2018. Agriculture 4.0: Broadening Responsible Innovation in an Era of Smart Farming. Frontiers, online at https://www.frontiersin.org/articles/10.3389/fsufs.2018.00087/full (Accessed February 2019). .

Rose, D.C., Parker, C., Fodey, J., Park, C., Sutherland, W.J., Dicks, L.V., 2018. Involving stakeholders in agricultural decision support systems: improving user-centred design. Int. J. Agric. Manag. 6, 80–89.

Rossel, V., Bouma, J., 2016. Soil sensing: a new paradigm for agriculture. J. Agric. Syst. 148, 71–74.

Schimmelpfennig, D., 2016. Farm Profits and Adoption of Precision Agriculture. ERR 217, U.S. Department of Agriculture, Economic Research Service. October 2016https://www.ers.usda.gov/webdocs/publications/80326/err-217.pdf?v=42661(Accessed August 2018).

Schlaile, M., Urmetzer, S., Blok, V., Andersen, A., Timmermans, J., Mueller, M., Fagerberg, J., Pyka, A., 2017. Innovation systems for transformations towards sustainability? Taking the normative dimension seriously. Sustainability 9, 2253.

Scholten, M.C., de Boer, I.J.M., Gremmen, B., Lokhorst, C., 2013. Livestock farming with care: towards sustainable production of animal-source food. Wageningen J. Life Sci. 66, 3–5.

Statistics Canada, 2016. Census of Agriculture. Retrieved from https://www150.statcan.gc.ca/n1/pub/95-640-x/95-640-x2016001-eng.htm (Accessed February 2019). .

Stilgoe, J., Owen, R., Macnaughten, P., 2013. Developing a framework for responsible innovation. Res. Policy 42, 1568–1580.

Stirling, A., 2011. Pluralising progress: from integrative transitions to transformative diversity. Environ. Innov. Soc. Transit. 1, 82–88.

Sundmaeker, H., Verdouw, C., Wolfert, S., Perez, L., 2016. Internet of food and farm 2020. In: Vermesan, O., Friess (Eds.), In Digtising the Industry-Internet of Things Connecting Physical, Digital and Virtual Worlds. River Publishers, Gistrup, Denmark and Delft, The Netherlands, pp. 129–151.

Tanahill, R., 1973. Food in History. Three Rivers Press, New York, NY.

Touzard, J., Temple, L., Faure, G., Triomphe, B., 2015. Innovation systems and knowledge communities in the agriculture and agrifood sector: a literature review. J. Innov. Econ. Manage. 117–142.

Walton, J., Larson, J., Roberts, R., Lambert, D., English, B., Larkin, S., et al., 2010. FactorsInfluencing farmer adoption of portable computers for site-specific management: ACase study for cotton production. J. Agric. Appl. Econ. 193–209.

Weersink, A., Fraser, E., Pannell, D., Duncan, E., Rotz, S., 2018. Opportunities and challenges for big data in agricultural and environmental analysis. Annu. Rev. Resour. Econ. 10, 19–37.

Welsh, R., Glenna, L., 2006. Considering the role of the university in conducting research on agri-biotechnologies. Soc. Stud. Sci. 36, 929–942.

Wiek, A., Foley, R., Guston, D., Bernstein, M., 2016. Broken promises and breaking ground for responsible innovation: intervention research to transform business as usual in nanotechnology innovation. Technol. Anal. Strateg. Manag. 28, 639–650.

Wilson, G., 2001. From productivism to post-productivism and back again? exploring the (un)changed natural and mental landscapes of European agriculture. Trans. Inst. Br. Geogr. 26, 77–102.

Winner, L., 1986. Do artifacts have politics? Daedalus 109, 121–136.

Wolf, S., Wood, S., 1997. Precision farming: environmental legitimation, commodification of information and industrial coordination. Rural Sociol. 62, 180–206.

Wolfert, X., Ge, L., Verdouw, C., Bogaardt, M., 2017. Big data in smart farming: a review. Agric. Syst. 153, 69–80.

Wong, Y.C., Fung, J.Y., Chu, M., Law, C.K., Lam, J.C., Wan, V., Ping, Lee, 2009. Tackling the digital divide. Br. J. Soc. Work 39, 754–767.