"If they don't tell us what they do with it, why would we trust them?" Applying the multi-level perspective on socio-technical transitions to understand trust, transparency and benefit-sharing in Smart Farming and Big Data

Emma Jakku[a], Bruce Taylor[a], Aysha Fleming[a], Claire Mason[b], Simon Fielke[a], Peter Thorburn[c], Chris Sounness[d]

[a]*Commonwealth Scientific and Industrial Research Organisation (CSIRO) Land & Water, emma.jakku@csiro.au; bruce.taylor@csiro.au; aysha.fleming@csiro.au; simon.fielke@csiro.au*

[b] *CSIRO Data61, clair.mason@data61.csiro.au*

[c] *CSIRO Agriculture & Food, peter.thorburn@csiro.au*

[d] *Birchip Cropping Group, chris@bcg.org.au*

Abstract: *Advances in Smart Farming and Big Data applications have the potential to help agricultural industries meet productivity and sustainability challenges. However, these benefits are unlikely to be realised if the social implications of these technological innovations are not adequately considered by those who promote them. Big Data applications are intrinsically socio-technical; their development and deployment are a product of social interactions between people, institutional and regulatory settings, as well as the technology itself. This paper explores the socio-technical conditions that influence the development of Smart Farming and Big Data applications, using a multi-level perspective on transitions. We conducted semi-structured interviews with 26 Australian grain farmers and industry stakeholders to elicit their perspectives on benefits and risks of these changes. The analysis shows that issues related to trust are central concerns for many participants. These include procedural concerns about transparency and distributional concerns about who in the supply chain will benefit from access to and use of "farmers' data". These concerns create scepticism about the value of these technologies amongst some industry stakeholders, especially farmers. It also points to a divergence of expectations and norms between actors and institutions at the regime and niche levels in the emerging transition towards Smart Farming. Bridging this divide will require niche level interventions to enhance the agency of farmers and their local networks in these transactions, and, the cooperative design of new institutions at regime level to facilitate the fair and transparent allocation of risk and benefit in farming data information chains.*

Keywords: *Multi-Level Perspective, socio-technical transitions, Big Data, digital agriculture, Australia, grains industry*

Introduction

Advances in Smart Farming (also known as digital farming or digital agriculture) and Big Data applications have the potential to deliver a range of benefits, such as improved decision-making, increased efficiency and economic gain and even decreased environmental impact, which could in turn help agricultural industries meet their productivity and sustainability challenges (Everingham et al., 2016; Sonka, 2016; Wolfert et al., 2017). Smart Farming takes advantage of emerging smart machines, sensors and precision agriculture equipment that create vast amounts of real-time farm data (e.g. monitoring animals, soil, water and plants) and uses this data to make more timely or accurate decisions, both on-farm and across the supply chain (Eastwood et al., In press; Wolfert et al., 2017). Big Data refers to the capability to extract information and insights at a large scale where previously it was economically and technically not possible (Sonka, 2015), through the use of “computerised analytical systems that interrogate extremely large databases of information in order to identify particular trends and correlations” (Keogh and Henry, 2016: 4). Big Data is often described in terms of the 3 Vs: Volume; Velocity; and Variety (Kitchin and McArdle, 2016; Manyika et al., 2011). Big Data applications are already being deployed to improve productivity and profitability in many sectors (Davenport and Dyché, 2013; Kitchin, 2014; van Rijmenam, 2017). Early experiences with Big Data applications in agriculture suggest that their success hinges upon multiple social and technical factors, including the willingness of stakeholders to share and integrate data, end-user acceptance of the technologies, and the existence of protocols for protecting farmers’ rights to privacy, data ownership and control (Eastwood and Yule, 2015; Griffith et al., 2013; Kaloxylos et al., 2014; Poppe et al., 2015; Sonka, 2015). Furthermore, Big Data applications have the potential to transform roles and power relationships between stakeholders within the agricultural sector (Bronson and Knezevic, 2016; Wolfert et al., 2017).

Consequently, Big Data applications are socio-technical, their development and deployment being a product of social interactions between people, institutional and regulatory settings, as well as the technology itself (Vines et al., 2013). In this respect, Big Data applications are similar to other agri-environmental decision-support technologies, or farming practices more broadly, that rely upon stakeholder collaboration (Carberry et al., 2002; Jakku and Thorburn, 2010) and trusted local networks and intermediaries that buffer farmers’ perceived risks and enhance local benefits (Taylor and Van Grieken, 2015). These dynamics occur within and across nested levels of social, institutional and cultural organisation that are tied to processes of innovation and transitions in society. To address what we argue is presently an empirical gap in understanding these emerging dynamics as they relate to digital disruption in Australian farming, we employ a multi-level perspective on transitions in the Australian grains industry. The aim of our research was to explore the socio-technical factors that influenced stakeholder expectations about Big Data applications. Our key research questions were: (i) what are the socio-techical conditions that assist the effective and acceptable use of digital agriculture and Big Data applications; and (ii) how might these technologies enhance or disrupt existing social and economic relationships in the agriculture sector? We examined the socio-technical factors that influence the impacts of Big Data applications at multiple levels, from the micro (the farmer and the technology developer) to the meso and macro (regulatory settings and institutional arrangements).

Conceptual framework: Multi-level perspective on socio-technical transitions (MLP)

This research uses the multi-level perspective on socio-technical transitions (MLP) (Geels, 2002; Geels, 2004; Geels, 2012; Schot and Geels, 2008) as a conceptual framework to guide our investigation of stakeholder dynamics surrounding the risks and benefits of Big Data applications. The MLP approach was designed to provide “analytical and heuristic concepts to understand the complex dynamics of sociotechnical change” (Geels, 2002: 1259), making it a useful framework for understanding socio-technical factors related to emerging technologies. The MLP approach identifies three nested hierarchical levels of a socio-technical system: niche innovations (micro level); regimes (meso level) and landscapes (macro level), as illustrated in Figure 1.

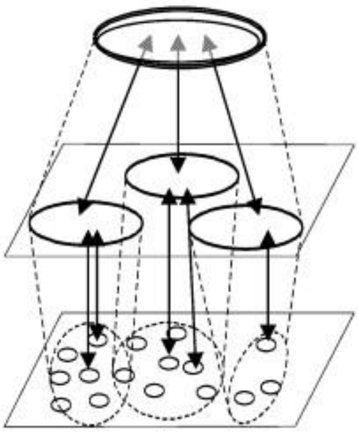

Figure 1. Multiple levels (niches, regime, landscape) of a socio-technical system form a nested hierarchy (Nykvist and Whitmarsh 2008: 1375, adapted from Geels, 2002)

The socio-technical *landscape* represents the overarching level. It represents the wider context of macro, long-term economic, political, cultural and environmental trends and material context (e.g. physical infrastructure, population growth, economic development, resource availability, political ideologies and dynamics, societal values, climate change) (Geels, 2002; Geels, 2004).The socio-technical *regime* level refers to the dominant and relatively stable systems of interacting practices, social structures and institutional elements (e.g. cognitive routines, shared belief systems and expectations, as well as normative, regulative and formal rules) that shape the activities of relevant actor groups (Geels, 2002; Geels, 2004). Micro-level *niches* are protected spaces (e.g. R&D laboratories, demonstration sites) where radical novelties (innovations) are generated, incubated and developed.

The MLP approach includes a focus on *socio-technical transitions*, defined as major shifts in structures, cultures and practices such that the way societal functions are fulfilled is profoundly altered (Geels, 2002; Ingram, 2015). As illustrated in Figure 2, the central notion of the MLP approach to socio-technical transitions is that these are non-linear, co-evolutionary processes that result from the interplay of multiple developments across these three analytical levels: “(a) niche innovations build up internal momentum, (b) changes at the landscape level create pressure on the regime, (c) destabilisation of the regime creates windows of opportunity for niche innovations“ (Schot and Geels, 2008: 545).

The MLP approach helps make sense of the complex socio-technical dynamics and processes that must align in order for novel technologies to successfully disrupt the existing regime. The MLP has been applied to a variety of contexts, including agro-ecological innovations (Wigboldus et al., 2016), algae blooms (Diaz et al., 2013), low-carbon transitions (Geels, 2012), transport systems (Nykvist and Whitmarsh, 2008) and urban water systems (Quezada et al., 2016).

Despite this utlity, there has been constructive discussion in the literature on some of the limitations of MLP in examining the social dimensions of those transitions (Hinrichs, 2014; Ingram, 2015; Raven et al., 2011; Shove and Walker, 2010; Wigboldus et al., 2016). Hinrichs (2014) in particular, in exploring transitions to sustainability in food systems, has agrued how a *social practices* perspective can complement a multi-level perspective, and when used together can improve our analytical and explanatory purchase on food systems change. Following Hinrichs (2014: 143) we recognise the importance and influence of “normal everyday routines and practices” the “possibilities of shifting these (or not)” and their relationship to politics, governnace, values and ethics. That is, in our approach we focus on those social and institutional factors that influence uptake and outcomes associated with technology. These include actors’ experiences with and perceptions of the risks and benefits of the technology and the extent to which the technology is seen to be compatible with existing farming or industry practices, routines and relationships (Pannell et al., 2006; Rogers, 1995; Vanclay and Lawrence, 1994). Indeed recent scholarship has examined the ways in which digital farming technologies are accommodated within and modify the everyday lives, practices and identities of farmers (Carolan, 2016; Higgins et al., 2017).

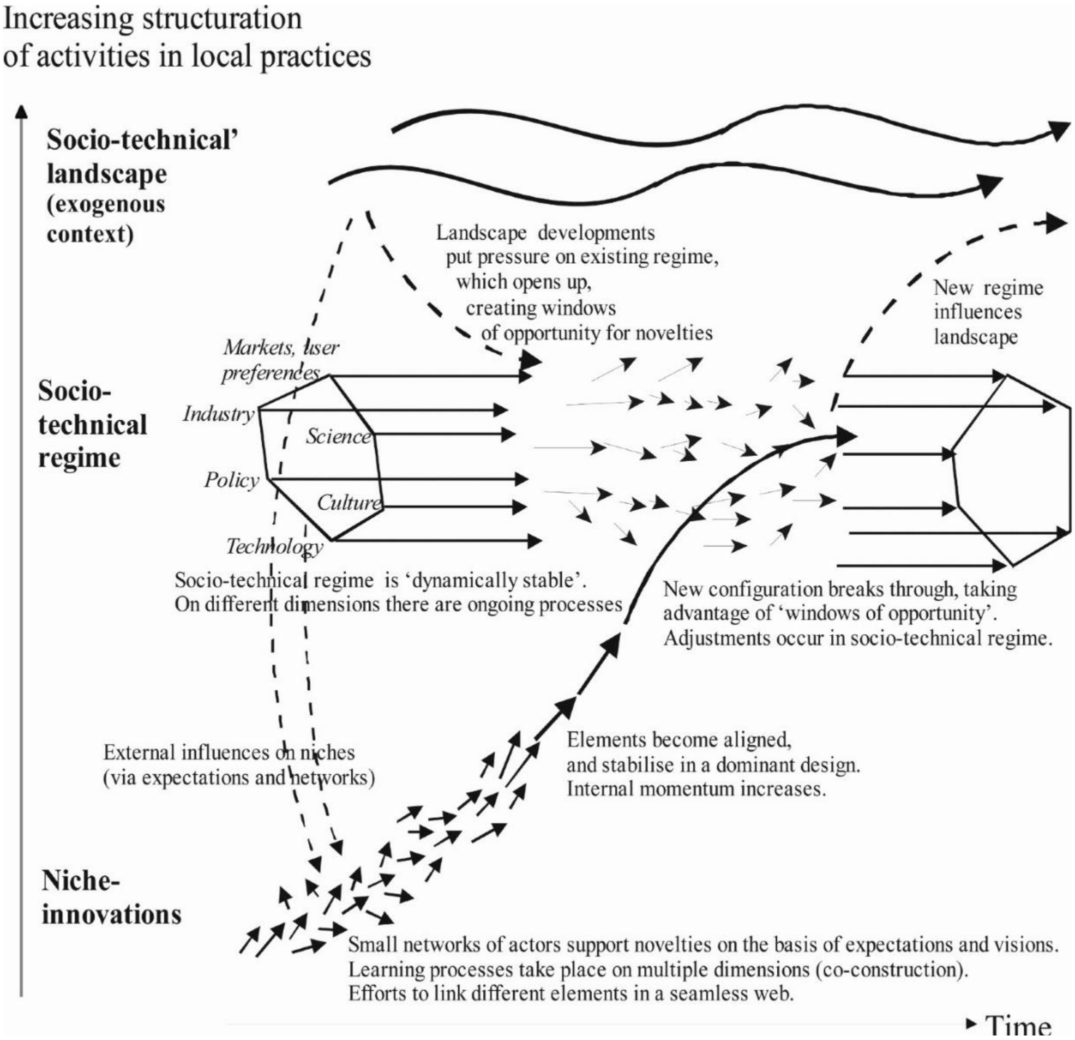

Figure 2. Multi-level perspective on socio-technical transitions (Schot and Geels, 2008: 546)

Therefore, for the purposes of this study we approximate digital technology related experimentation and uptake on individual farms or local, place-based networks of farms, as the empirical site of an emerging innovation niche. Similar to Ingram (2015) in relation to the importance of niche-regime interactions, we recognise that there are multiple actors engaged with farmers through supply and information chains (e.g. scientists, advisors, retailers, cooperatives, industry organsiations etc.) and that, in our conceptualisation, these actors directly and indirectly connect these innovation niches with regime-level structures and norms.

Methodology

Our research adopted a broadly interpretivist, qualitative approach, which allowed us to identify and explore different actors' perceptions of, and experiences with Smart Farming and Big Data applications in the Australian grains industry. Through in-depth interviews with diverse public, private and non-government organisation actors in the grain farming industry, we sought to elicit:

(i) Characteristics of the multiple stakeholders and end users and multiple technologies, e.g. how do different stakeholders understand Big Data applications and their associated risks and benefits (*niche level*)?

(ii) Multiple contexts of use of the technologies, e.g. how do Big Data applications integrate (or not) with existing practices (*regime level*) and emerging trends (*landscape level*) in the agricultural sector?

Since the applications of Big Data are likely to vary across different agricultural sectors, we chose to focus on one of Australia's largest agricultural industries where Big Data applications are emerging, namely, the grains sector. The grains sector makes an important contribution to the Australian economy, with the production of grains, oilseeds and pulse crops accounting for around 23 per cent ($13 billion) of the total gross value of farm production and around 24 per cent of the total value of farm export income in 2015–16 (ABARES, 2017). Grain production (predominantly wheat) occurs across a wide range of distinct agroecological zones, each with different climate and soil characteristics (Guthrie et al., 2017). Family farm ownership continues to dominate Australian grain production with more than 95% of grain farms being family owned and operated (Kalisch Gordon, 2016). The Australia grains sector is an example of an industry that has had to embrace niche innovation at the farm level in the past in order for farms to remain viable in an unprotected market and mitigate the risk of significant climatic variability. Innovation examples include the uptake of no-till farming, GPS technologies for auto-steer and, more recently, modest rates of adoption of precision agriculture approaches, such as variable rate fertiliser application (Robertson et al., 2012). Practices can change rapidly in order for grain farmers to remain competitive and as such it provides an interesting case study industry with a history of niche innovations taking off.

With the help of subject matter experts known to the researchers, we identified the key supply chain actors in the grains industry. We selected interviewees using a purposive sampling approach (Patton, 1990), collaborating with key informants to identify and recruit participants from different sectors within the grains industry and with different levels of involvement with digital technologies. Participants were invited via email and a follow-up phone-call. We conducted semi-structured interviews with 26 grains industry participants (23 men and 3 women): 14 participants were from the dryland broad acre and mixed farming systems of the Wimmera-Mallee region (in the southern state of Victoria), providing regional level grains sector insights; and 12 participants represented a cross-section of other industry stakeholders from the state and national level (see Table 1).

Table 1. Interview participants by stakeholder category

Stakeholder category	Number of participants		
	Wimmera-Mallee region	Other	All participants
Input provider	1	3	4
Grower	5	0	5
Grower group	4	4	8
Research & consulting	1	2	2
Logistics & trading	1	1	2
Local government	2	0	2
State government	0	2	2
Total	14	12	26

The Wimmera-Mallee region was selected because the region is engaged in active discussions about the future of digital agriculture. At the time of the interviews a key local grower group with a strong innovation record – the Birchip Cropping Group, a farmer-led agricultural research and extension organisation – was exploring opportunities for setting up a data co-operative, while the local council was developing a digital futures strategy. In the Wimmera-Mallee Region there is approximately 3 million hectares of dryland cropping and livestock country predominately cropped (approximately 75%). There are approximately 4000 family farms in the region and they make up the vast majority of landholders. Farm size ranges from very small (under 200 hectares) to over 5000 hectares, with some up to 10000 hectares. The Birchip Cropping Group has 430 family farms as members, farming approximately 1 million hectares. A typical membership consists of two family units farming the land together. Often both families will have children back on the farm or expecting to be back on the farm shortly. Farm size is mostly commonly between 2000 to 4000 hectares.

Interviews were generally one hour in duration and nine were conducted face-to-face in the Wimmera-Mallee region in February 2016, while the remaining 17 interviews were conducted via telephone between January – March 2016. The interviews started by covering some background information on individual participants. This was followed by questions about their place within the grains industry supply chain and their views on information flows and relationships among key players. Next, the interviews explored perceptions of digital agriculture and Big Data, prompted by the following questions: (i) what does Big Data and digital agriculture mean to you?; (ii) how much is Big Data part of your current business or future strategy?; (iii) what benefits or opportunities do these digital technologies and Big Data applications provide?; and (iv) what problems or risks do they present? The final section explored ideas about how these risks might be managed or reduced and some final reflections on the future of digital technologies and Big Data in the grains industry.

The interviews were audio recorded and transcribed. We used the qualitative data analysis software QSR NVivo® (QSR International, version 10) to aid the coding, analysis and management of the data. Interview transcripts were analysed using iterative thematic analysis (Grbich, 2007), whereby the data are categorised into a hierarchical structure of themes and sub-themes through multiple rounds of coding, informed by (and informing) our conceptual framework.

Results

Emerging niche innovations: stakeholder expectations of benefits and risks of Big Data applications at the niche level

Micro-level niches are protected spaces where small networks of actors support (or choose not to) the development of innovations on the basis of their expectations and visions. To understand how stakeholders' expectations were shaping the progress of Big Data applications in agriculture at the niche level, we analysed the way in which stakeholders described the potential benefits and risks associated with these new technologies.

On-farm benefits

On-farm benefits were the most frequently mentioned type of benefits associated with emerging Big Data applications. Interviewees outlined a range of ways in which Big Data could improve farm management and decision-making, focusing on improved efficiencies through more targeted applications of on-farm inputs:

> Well, benefits are more targeted application of inputs across our farms, so if we have the data to be able to aid in decision making then we can match our inputs to the potentials of the season. Not only on a paddock scale but down to a pixel scale or a particular point on the farm. (Grower group 8)

A related theme was the increased productivity and profitability that improved farm management and decision-making could bring: "…farmers make lots of decisions through the life of their crop on a farm, and if they can make better decisions…they are able to improve their efficiency and productivity out of that" (Input provider 3). The value of real-time information for decision-making was also highlighted as a potential benefit associated with advances in digital agriculture, especially sensing technologies: "So having a system - it might only be one or two weather stations on a property - that feeds in almost real time data to the farmer; would be really useful" (Grower group 6). Future benefits of Big Data were expected from linking-up current or future data sets, such as soils, climate projections, weather forecasts, water models and crop information on an individual farm basis.

Several participants expressed views that the efficiencies enabled by Big Data would mean higher prices for growers at the farm gate, although this view was not always supported by growers themselves:

> So digital agriculture, for me, is the automation of a lot of management processes for farmers largely, I don't think that you could necessarily automate much more of the supply chain. So it…is the next productivity gain pre-farm gate, it means that growers more take a role of managing their farm and putting prescriptions in place to automate those processes, [such as] a sprayer going out and spraying without a human actually sitting in it… (Grower group 4)

Industry and supply chain benefits

Interviewees also identified a number of potential industry and supply chain benefits, particularly those related to optimisation along the supply chain and the improved industry-level decision-making that this could bring: "I think, the supply chain will streamline itself and will be able to drive efficiencies from the use of Big Data, so there'll be a commercial benefit for the business" (Grower group 4). Another important benefit associated with Big Data was improved predictive and analytical capabilities for storage and transport logistics providers: "Certainly through logistics…being able to track, maintain, record is important for supply chain optimisation. …So at every level it will drive improved performance" (Grower group 3).

More accurate tracking and predictions of yield would allow for better optimisation of decisions and resource allocation related to transport, logistics, labour, timing and price points (Sonka, 2016). One interviewee referred to this as visibility along the supply chain where there may have been unknowns before, such as when grain was transported or combined with other growers' grain:

> The marketers want to keep data separate to get commercial advantage whereas [from a logistics and handlers' supply chain perspective]…greater visibility and accuracy around that data is what we're chasing. (Logistics and trading 2)

Big Data applications could also increase the traceability of grain in the supply chain, creating value for consumers, retailers and processors as well as growers:

> Traceability is the one that everyone talks about, so traceability is a good example because we're seeing increasing demand for people who understand where their food came from. The digital technology will enable that. (Input provider 1)

Similarly, one grower described how information on varieties of grain (including GM varieties, provenance, quality) could now be traced by customers, creating premium products and niche markets with potential to grow demand for specialist products (e.g. grain for craft brewing).

Improved crop forecasting data was reported as another potential future benefit of Big Data. Interviewees noted that the ability to gather and analyse data on variety, quantity, location, quality, weather events, management decisions and market prices offers a whole new way of understanding the grains industry. However, support will be required to improve the capacity to interpret the data in order to answer specific questions, for example to compare years and management decisions, as well as to look at non-traditional indicators to open new market niches.

Concerns about reliability and data accuracy

Despite the potential benefits of Big Data applications, interviewees also identified a range of risks. One common theme that emerged was that Big Data applications are novel and immature technologies. The 'teething problems' often associated with new technologies, combined with concerns about data accuracy, made people wary about how the reliability of emerging Big Data applications:

> But given this is…a relatively new field, it is going to take some time to get that validation and to get the systems working at a high level of accuracy. So that's I think one of the challenges over time that farmers are going to need to be able to work with systems that might not be perfect, but as they work with them, they will get better. (Input provider 3)

A related risk here was the challenges of data storage and handling in the context of a new and emerging technology:

> So we've got a lot of data that we've been collecting. And where we can use it, we do. But we really haven't found an easy outlet for that. And I think that's one of the things that the Big Data problem's created. There's just lots of information, which we know we need to collect to be able to get enough to be useful, but we don't know what to do with it and we should have enough by now to be useful. (Grower 3)

The transferability and applicability of the new technologies were another related area of concern, including the difficulty of making judgments about competing technologies in this domain:

> …there's at least half a dozen companies [in the United States] offering precision, prescription farming services for farmers to deal with, typically nitrogen in corn. …So those sorts of services are going to come here eventually, and how does a farmer evaluate whether the Pioneer solution is better than the Monsanto solution…? (Grower 1)

Socio-technical regimes: stakeholder expectations about benefits and risks of Big Data applications at the regime level

Socio-technical regimes are the dominant systems of actors, insititutions, practices and shared assumptions. One of the ways that regimes exert influnce on emerging niche innovations is via the shared assumptions, expectations and networks that make up the dominant regime. We analysed stakeholders' discussion of risks, benefits and factors that would need to be managed in order to support the uptake of Big Data to identify how regime level factors were seen to influence the diffusion of Big Data applications in agriculture.

Supply chain dynamics

Bulk handlers described the potential for value generation from collaboration between companies involved in grain storage and transport. One handler described the benefits of data-driven predictive modelling of the location, timing, volumes and quality of grain yields for informing decisions on rolling stock and road transport. The efficiency of the system overall, including managing grain flows into the port terminals, could be improved by co-investment across grain handling companies in a given region in generating a 'complete' picture of where and when grain was moving. However, investment in such a system by one company alone was seen as unviable. This supports commentary in the literature that collaboration across firms and organizations will be necessary in order to fully realise the potential benefits of Big Data applications in agriculture (Sonka, 2016).

Interviewees also noted that digital agriculture data in Australia is highly fragmented and people are not currently maximising existing data. A related issue here is the challenge of interoperability (the ability of information technology systems to exchange and make use of information), which is compounded by the fragmented nature of Australia's digital agriculture data landscape:

> …it's like different railway systems. In the end, it's sometimes easier to do it your own way than find a compromise. And I think that goes back to trust and everything like that. It's how much are you willing to give up and how much are you willing to drive forward? (Research & consulting 3)

Furthermore, while there is potential for Big Data applications to aid decision-making at both the on-farm and broader industry level, the greatest financial returns on implementing Big Data approaches were largely reported to be tied to businesses upstream and downstream of the farm gate (i.e. input suppliers and manufacturers, traders and marketers), rather than farmers themselves (see also Fleming et al., 2018). Marketers and traders expected that Big Data would allow them to better predict export demand and prices, however growers expressed concerns that this would, they believed, exacerbate the commercial advantage these groups currently exercised over growers. This raises questions about the value proposition of these new techologies and the distribution of benefits, which in turn shape perceptions of these technologies and their potential implications for stakeholder relationships in the agricultural sector. We will return to these themes later in this section.

Data privacy and security

The adequacy of regulations and practices to protect the privacy and security of farmers‘ data was another regime factor that was mentioned by several participants. Some interviewees were satisfied that privacy and security measures would be adequate:

> So we have privacy policies that are inserted into our licensing agreements with growers on an annual basis. And they obviously take into account federal and state requirements. And we update them as there are any changes in local requirements in Australia around privacy. (Input provider 3)

However, other interviewees expressed more concern:

> …All that privacy stuff, it's just can of worms. And it's got the potential to completely explode. But we are so reliant on our technology nowadays, that we can't really stop it. …So definitely some healthy scepticism and concern about how that sort of privacy can go. And I think people just need to become more and more aware of it - me included. And making those safeguards to make sure that you can protect your data. (Grower group 6)

Moreover, even with privacy and security measures in place, breaches are always going to be a risk:

> …I think that it is incumbent upon organisations that are storing data that they need to be doing their very best to maintain that security, but at the same time the consumers and the farmers need to understand that there can be breaches that happen from time to time even with the best intentions. And that's always going to be a risk. (Input provider 3)

Data ownership, data sharing and the distribution of benefits

The ability of regulation and practices to protect data ownership (and third party use and benefit from farmers‘ data) was one regime factor that was seen to be highly relevant for the uptake and adoption of Big Data applications. Data was understood as a valuable commodity, hence data ownership was important: "I have to admit everyone seems caught up in that data will be valuable therefore I should focus on owning it and extracting insight from it" (Input provider 1). Many growers were concerned that large corporations could capture this value, possibly at the expense of local growers, based in part on observations about how these issues are playing out in the United States:

> Now, if there is value in it you kind of want to make sure that if we're doing all this, we want a little bit of something back and I guess the fear is the big players swoop down, grab it, run off and make some big business model and they make a good living off it and the guys that generate it all miss out. …I'm of the thinking that we're probably at the bottom of the food chain. We've got something that maybe someone wants collectively and if they get it for nothing it just doesn't feel right. (Grower 4)

Many interviewees expressed uncertainty about rights to data ownership and use:

> It would be…really good to know how the information could be misused…actually that's probably as relevant as anything, to be honest, the risk side of it, how could it be misused, so then we can make an informed decision about where it goes and how it's used. (Grower 2)

Competing views were particularly evident regarding the principle that growers own their on-farm data. Some interviewees accepted digital agriculture service providers' assurances that growers' retained ownership of their on-farm data under emerging Big Data opportunities. For example, this interviewee discussed the approach taken by one major company to ownership of farm data:

> But effectively what [the company] has said is that if data is generated by a farmer or from their farming equipment on their farm, that that data is owned by the farmer. … And…if a farmer brings their data to [the company] or they generate it through their equipment and it's used as part of [the company's] systems, if the farmer wants to leave, they can take their data with them, and we don't own that data. …That's why I do really like the guiding principles that [the company] have put in place. (Input provider 3)

However, other interviewees expressed a more critical view, focusing instead on how that data may be used and who it might be used by. Thus, trust in (as well as the existance of) data ownership regulations is another component of this regime level factor:

> They [digital agriculture service providers] say the farmer owns the data, the farmer, legally that's true but practically what does it mean? Almost nothing. A far more interesting and pertinent question is what are they doing with that farm data? (Grower 2)

Digital agriculture service providers seek to address concerns about privacy and data ownership through written contracts, which specify the terms and conditions regarding data ownership and use (Keogh and Henry, 2016). The lack of trust expressed above is in part due to the way in which some user agreements "bury exclusions deep in the document which in effect give free reign to the software providers…to use the data in many different ways, including via the sale or transfer of the data to a third party" (Keogh and Henry, 2016: 37).

However, the lack of trust also reflects established belief systems and normative roles between farmers and agribusiness. Several participants referenced the unequal power relations that were seen to exist between farmers and large businesses:

> But it depends on how the information is going to be disseminated once it's collected as well and who has control of it. And that's one of the areas that really worries me is that it seems to me that most farmers are still reasonably small and most of the businesses they deal with are reasonably large so there's going to be an inequity in the data. (Local government 1)

Concerns around data ownership and use also related to the boundaries around what data growers are comfortable with sharing and what data they want to protect:

> I'd be more worried about that…when you sign the dotted line to buy that tractor you lose control of the data without really realising it. … Well I think one farmer versus [a large company], we've got Buckley's. …[T]he information about how many hours our tractors do, what sort of conditions do they work in, what problems they have, that's all great information to have. [The large company] needs that information to build better tractors, more efficient, which is going to benefit us. I think the data that we have that's most value to other people is our yields, our varieties that are much more specific to our farms. Our gross margins, our business information. And that we should be more able to keep control of. (Grower group 6)

As a consequence, some interviewees raised doubts about the willingness of growers to share their on-farm data, even with other growers:

> But I can't see people openly sharing their data. I can see people giving you a bit of something that you might need, or sitting down with your agronomist, giving them some stuff. But I can't see me and you, being farmers that are 100km away, really, openly sharing. We might talk on basics, but I'm never going to let you take my yield maps and you're never let me take yours. We might look at them together and talk about different farming methods and the physical, but you're never going to walk away with that data, I wouldn't have thought. (Input provider 4)

It was clear that the perceived adequacy of data ownership and third party benefit regulation, along with inequalities and lack of trust between farmers and large agribusinesses was directly connected with willingness to adopt Big Data applications that involve data sharing: "I think the risk lies in farmers being confident that they don't need to lock up their data and make it absolutely unavailable to anyone except a very narrow limited range of providers" (Grower group 2). One interviewee pointed out that the industry needed to better explain the value proposition for access and use of on-farm data:

> …the industry has done, frankly, a terrible job of explaining why they want access to farm data. Not so much an issue probably here in Australia yet, it's probably just starting to happen now, but in the US it's been going on for quite a few years, and it's even more so. ….So it's this weird thing where they don't want to tell us exactly what they're doing with it but if they don't tell us what they do with it, why would we trust them? …[P]robably mostly they are doing the right thing but that's not explained anywhere and we're certainly just trusting that's what they say they're doing, there's no way of verifying it…and that's what's holding more farmers back from adopting it, but we miss out on the benefits of it then as well. (Grower 1)

Thus, issues of trust and transparency (normative roles between farmers and agribusinesses) have the potential to limit the adoption of Big Data applications. Lack of trust due in part to previous experience, can lead to apathy and withdrawal (Stern and Baird, 2015) and could in turn limit uptake of Big Data applications. Other researchers have identified that concerns over data sharing are also related to the dynamics of power relations between industry stakeholders (Avelino and Rotmans, 2009; Avelino and Wittmayer, 2015; Nelson and Tallontire, 2014; Wolfert et al., 2017).

Furthermore, interviewees also described Smart Farming and Big Data applications in terms which clearly echoed the nested character of transitions. One interviewee anticipated changes at macro-economic levels, through to everyday practices of managing a farm business:

> Step change is something that will be required in the Australian agricultural sector to remain internationally competitive. So looking at, you know, revolutionising the way we do things and not just finding those one, two percent gains around the fringes, which digital agriculture will help us with, but it could also help us make step changes in the way we farm and in the way we undertake business day to day. (Grower group 3)

Acheiving this step change, however, depends in part on factors at the socio-technical landscape level.

Socio-technical landscape: limitations and constraints

The socio-technical landscape is the exogenous context created by macro-level economic, ecological, political and cultural trends and material context. At this level, the fundamental limitations of Australia's digital infrastructure, especially in rural and regional areas, was one of the most significant risks to the success of Big Data applications identified by interviewees. There were widespread views amongst interviewees that the mobile phone network and internet access in rural Australia was not currently sufficient to support some of the potential advances in Smart Farming:

> …another risk is actually not having the ability to download all this data and actually upload stuff and have good internet coverage. …If we want this to happen in the country we've got to have our mobile phone working pretty much, and that's a major concern. (Grower 2)

Although one interviewee acknowledged that "there are work arounds" for the limitations to digital infrastructure (Grower 1), there remained a degree of scepticism about how much the rural and regional digital infrastructure would improve in the near future, which some interviewees linked to the further widening of the city/country divide:

> And our other big problem that's going to become more pronounced is just lack of Internet access… I'm not sure what's going to come out of the rollout of the NBN [National Broadband Network] but…we're going to be left off the end of that and a lot of this sort of stuff is going to be quite data hungry that we should and could be using. So I'm not sure what the answer to that is but it's certainly going to create a bigger city/country divide. (Grower 5)

Many participants made reference to the city/country divide, also referred to as 'regions falling behind' and geographic inequality. This deep cultural pattern was linked to issues of trust and inequality more generally, such as the belief that the benefits of Big Data would accrue to large corporations (urban entities) with farmers (rural actors) losing control of their own data and thus the benefits to be derived from it. It is therefore an aspect of Australia's cultural identity that may hinder the diffusion of Big Data applications and related innovations. The challenges surrounding rural and regional digital infrastructure and the growing divide in data infrastructure quality between urban and rural areas have been noted elsewhere and are a significant issue to overcome in the effort to build sustainable digital futures for rural and regional communities (Pant and Hambly Odame, 2017; Roberts et al., 2017; Salemink et al., 2017).

A potentially important landscape factor which is compatible with the adoption of Big Data in agriculture is climate change. As one interviewee observed:

> The challenges that the Australian grain industry faces, it's getting hotter and drier through all of our grain growing regions over the last 100 years...and…that comes back to less use and some good science to address those issues… (Logistics & trading 1)

The fact that water resources will be more constrained, that farmers will be dealing with changing climate conditions, increases the need for the improved information and efficiency that Smart Farming and Big Data applications will provide. In Australia, our scale and climate are also landscape factors which will support uptake of Big Data applications – farms tend to be very large so it will be an advantage to be able to collect and analyse data via sensors and Big Data applications. Our harsh climate and high variability also make it useful to be able to monitor conditions.

Discussion

Our study used the multi-level perspective on socio-technical transitions as a conceptual framework to unpack the many factors and dynamics affecting the development of Smart Farming and Big Data applications. For the grains industry stakeholders that we interviewed, Big Data applications were considered to be one of the most important developments in agriculture, offering the potential to transform Australian agriculture through significant productivity gains. By adopting the MLP framework, we were able to identify how social, institutional and technical factors, operating at multiple levels of analysis were seen to influence the potential diffusion of this important innovation for the agricultural sector.

At the niche level, a key factor supporting the uptake of Big Data applications was the widely held expectation that farmers would benefit from Smart Farming and Big Data applications, since they would be able to make better decisions through the insights enabled by this technology. The fact that these benefits were expected to accrue across the supply chain and even more broadly is likely to facilitate changes to processes and systems at the regime level. This confluence of benefits could be harnessed to support the collaboration required for effective use of Big Data applications, if potential barriers and risks of the kind identified in our study can be mitigated or managed. For example, the potential to derive national benefit from big data applications may support the collaboration and across firms and organizations and regional co-investment, which participants believed would be needed to support the diffusion of this innovation.

However, there are aspects of the regime which were less favourable to Big Data applications, in particular, the normative roles between farmers and agribusiness and between city and country, which was characterized by a lack of trust and unequal distribution of benefits and resources. Consequently, growers were concerned that disproportionate benefit from Big Data applications would accrue to businesses upstream and downstream of the farm gate (i.e. input suppliers and manufacturers, traders and marketers) and indeed believed that growers were most exposed to potential risks and exploitation of these technologies within supply chains already characterised by power assymetries.

The capacity of different grains supply chain actors to engage with or benefit from Smart Farming (including Big Data applications) is presently highly varied, especially amongst farm businesses. For the majority of growers we interviewed the benefits they receive are likely to be realised longer term or 'down the track' and in many cases appear uncertain. In the short to medium term, concerns about transparency, equity (in terms of the distribution of benefits) and access appear to dominate. Similar themes have emerged in other studies investigating digital transformation in the grains industry and the broader agricultural sector (Guthrie et al., 2017; Zhang et al., 2017). Indeed, trust and transparency are central themes underlying concerns surrounding stakeholder perceptions of the risks and costs associated with the use of on-farm data, which in turn have the potential to limit the informed and consensual participation of all stakeholders in Smart Farming and Big Data applications.

Conclusion and recommendations

The successful implementation of Smart Farming and Big Data applications depends not only on designing these applications but ensuring that the design and implementation of these technologies respond to stakeholder dynamics within the agricultural sector, including the way in which these novel technologies are understood, adopted and adapted by farmers and other decision-makers (Bronson and Knezevic, 2016; Sonka, 2016; Wolfert et al., 2017). Trusted information and advice networks are likely to be important mechanisms for growers in mediating the benefits and risks of engaging with these regime factors. As such, alignment of these new opportunities with existing (or re-negotiated) trust relationships is a critical enabling condition. Therefore, our primary recommendation is the need to invest in building the capability of growers and farm businesses to be both informed data consumers as well as co-creators and curators of data, by involving growers and their trusted information and advisory networks in the cooperative development and trialling of these systems. Such actions we argue would improve the articulation between the everyday practices and decisions of farmers at the niche level, with the networks, norms and structures of regime-level elements that enable or constrain possible transitions.

Key questions remain, for example: what are the implications of emerging and diverse models of services and governance of Smart Farming and Big Data applications, and how adequate are they at meeting the requirements of transparency, shared benefit and access raised in this study? We found that participants' views were divided on this point. Furthermore, since advances in Smart Farming are also likely to converge with a variety of information-based compliance processes (e.g. food safety and environmental regulation), it will also be necessary to understand how this regime level convergence is likely to impact on farm productivity related developments and the regulation of agricultural production and supply chains at the enterprise level.

There is an important role for social researchers working in a participatory way with industry, corporate and research, development and extension stakeholders to identify the complex factors and processes influencing the deployment of Smart Farming and Big Data applications, and how they are likely to interact in their effects. Such research will support their ongoing improvement, assess their transferability between sectors or growing regions and ultimately help to ensure that the application of these novel technologies has the widest possible benefit across the agricultural sector.

References

ABARES. (2017) Grain farms: Industry overview, URL: http://www.agriculture.gov.au/abares/research-topics/surveys/grains.

Avelino F., Rotmans J. (2009) Power in Transition: An Interdisciplinary Framework to Study Power in Relation to Structural Change. *European Journal of Social Theory* 12: 543-569. DOI: 10.1177/1368431009349830.

Avelino F., Wittmayer J.M. (2015) Shifting Power Relations in Sustainability Transitions: A Multi-actor Perspective. *Journal of Environmental Policy & Planning* 18: 628-649. DOI: 10.1080/1523908x.2015.1112259.

Bronson K., Knezevic I. (2016) Big data in food and agriculture. *Big Data & Society* January-June: 1-5.

Carberry P.S., Hochman Z., McCown R.L., Dalgliesh N.P., Foale M.A., Poulton P.L., Hargreaves J.N.G., Hargreaves D.M.G., Cawthray S., Hillcoat N., Robertson M.J. (2002) The FARMSCAPE approach to decision support: farmers', advisers', researchers' monitoring, simulation, communication and performance evaluation. *Agricultural Systems* 74: 141–177.

Carolan M. (2016) Publicising Food: Big data, precision agriculture, and co-experimental techniques of addition. *Sociologia Ruralis*: 1-20. DOI: 10.1111/soru.12120.

Davenport T.H., Dyché J. (2013) Big data in big companies, International Institute for Analytics, Portland, United States.

Diaz M., Darnhofer I., Darrot C., Beuret J.-E. (2013) Green tides in Brittany: What can we learn about niche–regime interactions? *Environmental Innovation and Societal Transitions* 8: 62-75. DOI: 10.1016/j.eist.2013.04.002.

Eastwood C., Klerkx L., Ayre M., Dela Rue B.T. (In press) Managing socio-ethical challenges in the development of smart farming: from a fragmented to a comprehensive approach for responsible research and innovation, Journal of Agricultural and Environmental Ethics.

Eastwood C., Yule I. (2015) Challenges and Opportunities for Precision Dairy Farming in New Zealand. *Farm Policy Journal* 12: 33-41.

Everingham Y., Sexton J., Skocaj D., Inman-Bamber G. (2016) Accurate prediction of sugarcane yield using a random forest algorithm. *Agronomy for Sustainable Development* 36. DOI: 10.1007/s13593-016-0364-z.

Fleming A., Jakku E., Lim-Camacho L., Taylor B., Thorburn P. (2018) Is big data for big farming or for everyone? Perceptions in the Australian grains industry. *Agronomy for Sustainable Development* 38. DOI: 10.1007/s13593-018-0501-y.

Geels F.W. (2002) Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case study. *Research Policy* 31: 1257-1274.

Geels F.W. (2004) From sectoral systems of innovation to socio-technical systems. *Research Policy* 33: 897-920. DOI: 10.1016/j.respol.2004.01.015.

Geels F.W. (2012) A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. *Journal of Transport Geography* 24: 471-482. DOI: 10.1016/j.jtrangeo.2012.01.021.

Grbich C.F. (2007) *Qualitative Data Analysis: An Introduction* SAGE International, London.

Griffith C., Heydon G., Lamb D., Lefort L., Taylor K., Trotter M. (2013) Smart Farming: Leveraging the impact of broadband and the digital economy, CSIRO and University of New England, New England.

Guthrie P., Henderson W., Sounness C. (2017) Connectivity, Capability, Trust: Creating Farmer Driven Traceability for Victorian Grain Exports Using Digital Agriculture, Birchip Cropping Group and Victoria State Government. pp. 1-57.

Higgins V., Bryant M., Howell A., Battersby J. (2017) Ordering adoption: Materiality, knowledge and farmer engagement with precision agriculture technologies. *Journal of Rural Studies* 55: 193-202. DOI: 10.1016/j.jrurstud.2017.08.011.

Hinrichs C.C. (2014) Transitions to sustainability: a change in thinking about food systems change? *Agriculture and Human Values* 31: 143-155. DOI: 10.1007/s10460-014-9479-5.

Ingram J. (2015) Framing niche-regime linkage as adaptation: An analysis of learning and innovation networks for sustainable agriculture across Europe. *Journal of Rural Studies* 40: 59-75. DOI: 10.1016/j.jrurstud.2015.06.003.

Jakku E., Thorburn P.J. (2010) A conceptual framework for guiding the participatory development of agricultural decision support systems. *Agricultural Systems* 103: 675-682. DOI: http://dx.doi.org/10.1016/j.agsy.2010.08.007.

Kalisch Gordon C. (2016) State of the Australian Grains Industry, GrainGrowers, Sydney. pp. 1-84.

Kaloxylos A., Groumas A., Sarris V., Katsikas L., Magdalinos P., Antoniou E., Politopoulou Z., Wolfert S., Brewster C., Eigenmann R., Maestre Terol C. (2014) A cloud-based Farm Management System: Architecture and implementation. *Computers and Electronics in Agriculture* 100: 168-179. DOI: 10.1016/j.compag.2013.11.014.

Keogh M., Henry M. (2016) The Implications of Digital Agriculture and Big Data for Australian Agriculture, Australian Farm Institute, Sydney, Australia.

Kitchin R. (2014) *The Data Revolution: Big Data, Open Data, Data Infrastructures and Their Consequences* SAGE, London.

Kitchin R., McArdle G. (2016) What makes Big Data, Big Data? Exploring the ontological characteristics of 26 datasets. *Big Data & Society* 3. DOI: 10.1177/2053951716631130.

Manyika J., Chui M., Brown B., Bughin J., Dobbs R., Roxburgh C., Hung Byers A. (2011) Big data: The next frontier for innovation, competition, and productivity, The McKinsey Global Institute.

Nelson V., Tallontire A. (2014) Battlefields of ideas: changing narratives and power dynamics in private standards in global agricultural value chains. *Agriculture and Human Values* 31: 481-497. DOI: 10.1007/s10460-014-9512-8.

Nykvist B., Whitmarsh L. (2008) A multi-level analysis of sustainable mobility transitions: Niche development in the UK and Sweden. *Technological Forecasting and Social Change* 75: 1373-1387. DOI: 10.1016/j.techfore.2008.05.006.

Pannell D.J., Marshall G.R., Barr N., Curtis A., Vanclay F.M., Wilkinson R. (2006) Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture* 46: 1407-1424.

Pant L.P., Hambly Odame H. (2017) Broadband for a sustainable digital future of rural communities: A reflexive interactive assessment. *Journal of Rural Studies* 54: 435-450. DOI: 10.1016/j.jrurstud.2016.09.003.

Patton M. (1990) *Qualitative Evaluation and Research Methods*. 2nd ed. ed. SAGE, Thousand Oaks, CA.

Poppe K., Wolfert S., Verdouw C., Renwick A. (2015) A European Perspective on the Economics of Big Data. *Farm Policy Journal* 12: 11-19.

Quezada G., Walton A., Sharma A. (2016) Risks and tensions in water industry innovation: understanding adoption of decentralised water systems from a socio-technical transitions perspective. *Journal of Cleaner Production* 113: 263-273. DOI: 10.1016/j.jclepro.2015.11.018.

Raven R.P.J.M., Verbong G.P.J., Schilpzand W.F., Witkamp M.J. (2011) Translation mechanisms in socio-technical niches: a case study of Dutch river management. *Technology Analysis & Strategic Management* 23: 1063-1078. DOI: 10.1080/09537325.2011.621305.

Roberts E., Anderson B.A., Skerratt S., Farrington J. (2017) A review of the rural-digital policy agenda from a community resilience perspective. *Journal of Rural Studies* 54: 372-385. DOI: 10.1016/j.jrurstud.2016.03.001.

Robertson M.J., Llewellyn R.S., Mandel R., Lawes R., Bramley R.G.V., Swift L., Metz N., O'Callaghan C. (2012) Adoption of variable rate fertiliser application in the Australian grains industry: status, issues and prospects. *Precision Agriculture* 13: 181-199. DOI: 10.1007/s11119-011-9236-3.

Rogers E.M. (1995) *Diffusion of innovations*. 4th edition. ed. The Free Press, New York.

Salemink K., Strijker D., Bosworth G. (2017) Rural development in the digital age: A systematic literature review on unequal ICT availability, adoption, and use in rural areas. *Journal of Rural Studies* 54: 360-371. DOI: 10.1016/j.jrurstud.2015.09.001.

Schot J., Geels F.W. (2008) Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management* 20: 537-554. DOI: 10.1080/09537320802292651.

Shove E., Walker G. (2010) Governing transitions in the sustainability of everyday life. *Research Policy* 39: 471-476. DOI: 10.1016/j.respol.2010.01.019.

Sonka S. (2015) Big Data: From Hype to Agricultural Tool. *Farm Policy Journal* 12: 1- 9.

Sonka S. (2016) Big data: Fueling the Next Evolution of Agricultural Innovation. *Journal of Innovation Management* 4: 114-136.

Stern M.J., Baird T.D. (2015) Trust ecology and the resilience of natural resource management institutions. *Ecology and Society* 20. DOI: 10.5751/es-07248-200214.

Taylor B.M., Van Grieken M. (2015) Local institutions and farmer participation in agri-environmental schemes. *Journal of Rural Studies* 37: 10-19. DOI: 10.1016/j.jrurstud.2014.11.011.

van Rijmenam M. (2017) Why UPS spends over $ 1 Billion on Big Data Annually, Datafloq. pp. Available from: https://datafloq.com/read/ups-spends-1-billion-big-data-annually/273.

Vanclay F.M., Lawrence G. (1994) Farmer rationality and the adoption of environmentally sound practices: A critique of assumptions of traditional agricultural extension. *European Journal for Agricultural Education and Extension* 1: 59-90.

Vines R., Jones M., McCarthy G. (2013) Collaborating across institutional and jurisdictional boundaries: enabling the emergence of a national innovation system through public knowledge management. *Knowledge Management Research & Practice* 13: 187-197. DOI: 10.1057/kmrp.2013.41.

Wigboldus S., Klerkx L., Leeuwis C., Schut M., Muilerman S., Jochemsen H. (2016) Systemic perspectives on scaling agricultural innovations. A review. *Agronomy for Sustainable Development* 36. DOI: 10.1007/s13593-016-0380-z.

Wolfert S., Ge L., Verdouw C., Bogaardt M.-J. (2017) Big Data in Smart Farming – A review. *Agricultural Systems* 153: 69-80. DOI: 10.1016/j.agsy.2017.01.023.

Zhang A., Baker I., Jakku E., Llewellyn R. (2017) Accelerating precision agriculture to decision agriculture: The needs and drivers for the present and future of digital agriculture in Australia. A cross-industry producer survey for the Rural R&D for Profit 'Precision to Decision' (P2D) project CSIRO, Australia.