Agricultural Systems 180 (2020) 102763

Contents lists available at ScienceDirect

Agricultural Systems

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

Review

Digitalisation of agricultural knowledge and advice networks: A state-of-the-art review

Simon Fielke*, Bruce Taylor, Emma Jakku

CSIRO Land and Water, Dutton Park, Queensland, Australia

ARTICLE INFO

Keywords:
Agricultural innovation systems
Agricultural advisory services
Connectivity
Transparency
Governance

ABSTRACT

Digitalisation is widely regarded as having the potential to provide productivity and sustainability gains for the agricultural sector. However, there are likely to be broader implications arising from the digitalisation of agricultural innovation systems. Agricultural knowledge and advice networks are important components of agricultural innovation systems that have the potential to be digitally disrupted. In this paper, we review trends within agricultural knowledge and advice networks both internationally and in Australia, to anticipate and prepare for potential transformations in these networks.

Through a combined structured and traditional review of relevant literature, we come to three key conclusions regarding the state-of-the-art. First, the connectivity of humans and technologies in agricultural knowledge and advice networks and value chains will likely continue to increase. Second, transparency of agricultural practices and informational interaction between farmers, advisors, agri-businesses, consumers and regulators will drive and be driven by growing connectivity. Finally, there are likely to be challenges balancing the priorities of various agricultural stakeholders as agricultural innovation systems digitalise. These findings have implications for the oversight of international agri-food sectors.

1. Introduction

Digitalisation involves the introduction of digital technological innovations into existing (organisational, industrial, societal) systems in such a way that changes how those systems operate. It is said to be one of the most significant trends globally at present (Leviäkangas, 2016). The digitalisation of everyday life will continue to result in the disruption of the currently powerful: technologies; individuals; organisations; and networks. Applied to agriculture, many of the proposed benefits of digitalisation centre on increased efficiency through precise mechanisation, automation, and improved decision-making. However, it is also likely that resulting industry-wide digital transformation will create existential questions for agricultural stakeholders as they learn to grasp new ways of working. This paper aims to improve clarity regarding the potential effects on agricultural knowledge and advice networks, institutional norms and governance, as agricultural systems digitalise, by considering interactions between technological developments and existing institutional settings (Paschen et al., 2017).

Much of the existing scholarship on the digitalisation of agriculture is dominated by fragmented and uncritical reporting of human-technology interaction beyond the farm.[1] Various individual digital agricultural innovations have been examined in respect to implications for rural and agricultural governance (for examples see: Carolan (2018); Eastwood et al. (2017b); Pant and Odame (2017)). Examination of the higher-level implications of converging technological developments for the agricultural sector are rarer. Similarly, while the underlying motivations of agricultural advisors, and relationships between public and private actors in the agricultural innovation system have been examined (Eastwood et al., 2017a; Nettle et al., 2018), scholarship is yet to holistically tackle the challenges and opportunities presented by digitalisation (Ayre et al., 2019). Agricultural advisors as intermediaries in agricultural knowledge and advice networks are a critical component of any agricultural innovation system (Klerkx and Leeuwis, 2009; Knierim et al., 2017). Advisors' knowledge-brokering and facilitation roles are also relevant in the context of the digitalisation of agricultural systems (Eastwood et al., 2019a). These service providers will need to adapt to operate at the intersection of cyber-physical systems as increasing data-driven power is held within the digital world due to autonomous information sharing, analytics and decision-making (Lioutas et al., 2019; Rose and Chilvers, 2018).

* Corresponding author.
E-mail address: simon.fielke@csiro.au (S. Fielke).

[1] See Supplementary data for 13 papers flagging some form of risk regarding the increasing digitalisation of agriculture and implications for governance at the time of the structured review.

https://doi.org/10.1016/j.agsy.2019.102763
Received 26 August 2019; Received in revised form 17 October 2019; Accepted 30 November 2019
Available online 10 January 2020

This paper reviews the state-of-the-art regarding likely effects of digitalisation on agricultural knowledge and advice networks as important but vulnerable elements of agricultural innovation systems (Grant and Booth, 2009). Specifically, we follow Klerkx et al. (2019) suggestion to undertake a structured review of the international literature in this space, to identify the more influential trends that have shaped, and continue to shape, rural extension and innovation. Utilising a more traditional review of the literature we then consider how emerging digital developments intersect with these trends to influence the future performance of agricultural knowledge and advice networks. By focusing our review on influential trends, it is possible to consider future implications of digitalisation for different actors or stakeholders in the agricultural sector (Dufva and Dufva, 2019). Developing an understanding of these trends and their implications can help agricultural stakeholders and policy-makers anticipate, and therefore steer toward or away from, transition pathways that are more or less desirable (Wilson, 2014). Similarly, this understanding will help individuals and organisations plan for a future in which their identites will be challenged by digital transformation (Rijswijk et al., 2019).

Our review of the literature and exploration of implications is international in its scope. However, to help contextualise the more significant trends to better understand their real-world implications, we include a specific focus on the Australian agricultural sector within the review. An Australian focus is useful as it presents two contrasting conditions of broader relevance. The first of these conditions is that whilst the influence of digitalisation on agriculture in Australia is relatively immature, there are calls for the prioritisation and rapid increase of public investment to meet productivity and sustainability targets moving forward (Leonard et al., 2017). In contrast to this call for greater public investment, the influence of neoliberal Australian agricultural policy has seen greater reliance on civil society and private market actors to address negative social and environmental outcomes and risks as well as an increasing demand for technical proficiency at farm-level (Baker, 2018; Lawrence et al., 2013; Wang et al., 2017). Regarding agricultural advisory services specifically, it has been argued that privatisation has led to increasing fragmentation within the agricultural knowledge and advice network (Nettle et al., 2018; Paschen et al., 2017). Networks of interested stakeholders are responsible for driving changes in behaviour in a manner like other heavily privatised developed nations through entrepreneurship and innovation (Pant and Odame, 2017; Schut et al., 2015). Our primary research question builds on this work to ask: how could existing trends in agricultural advisory service structure and potential digital developments influence the performance of agricultural knowledge and advice networks into the future?

The structure of the paper is as follows. In the following section we explain the two-fold state-of-the-art review process. We then provide some further definition to the concepts introduced briefly above in section 3: (i) digitalisation in agriculture and (ii) knowledge and advice networks within agricultural innovation systems. Then in section 4, we detail the major influential trends and sub-trends identified from the review and contextualise these trends in the Australian context. Then, drawing on both the international evidence and our Australian case, we propose and discuss three themes that could serve as important foci for future research on socio-technical dimensions of digital agriculture, namely: connectivity, transparency and governance.

2. Method

This state-of-the-art review takes a two-fold approach to identifying key sources that provide information to address the research question: how could existing trends in agricultural advisory service structure and potential digital developments influence the performance of agricultural knowledge and advice networks into the future? The two components of the review are:

1. A structured review of the implications of *digitalisation on agricultural institutions* and industry oversight internationally.
2. A more traditional snowball literature review and conceptual framing of *major trends and sub trends acting on agricultural advisory services*, with specific relevance to Australia as a case study country with developed agricultural industries facing change as a result of the digitalisation of agriculture.

The first line of enquiry utilised a structured review of the literature (Zscheischler and Rogga, 2015), which yielded 276 papers.[2] Paper titles, keywords and abstracts were queried for all *Scopus* listed journal articles published or in press for the search terms 'digital* OR smart OR precision' AND 'agricultur* OR farm*' AND 'institution* OR governance' (see appendix A). The intent was to ensure important sources outside of the key rural extension and innovation literatures were identified, and that an overview of publication activity on these topics over time could be quantified. Fig. 1 shows the significant increase in scholarship linking digital agriculture and/or smart farming to questions of agricultural governance and institutional change in the last decade.

Each of the 276 paper abstracts were read by the first author and scoped for relevance in terms of use of the three areas of focus – digital or smart or precision, agriculture or farming, institution or governance (Fig. 2). Such analysis determined that the vast majority did not consider all three term categories in a manner that made sense for a social scientist attempting to connect these themes, for example one of the term categories was used in depth but the other two were mentioned once or twice out of context. Fig. 2 shows the intersection of the three term categories with the 36 papers that were read in full for compatibility represented by the overlap of all three term categories.

After reading the 36 papers, a final reduction for lack of relevance followed, with 28 papers remaining. The quotes engaging with the digital agriculture component and institutional component of the search were drawn out of the 28 papers to create a two by two matrix for coding (see Supplementary data). This matrix situated papers in one of four quadrants. One axis grouped those papers with only positive sentiment toward digitalisation OR those with more nuanced sentiment (ie recognising concerns). The other axis grouped papers claiming institutions or governance were recognised as primarily either barriers/enablers OR as components of innovation systems. On developing Supplementary data, we came to the realisation that certain relevant literature was missing resulting in the subsequent review method utilising a more traditional, reflexive, snowball analysis of major literatures on extension and advisory services in agricultural and rural innovation (Pant and Odame, 2017; Wolfert et al., 2017).

Both these review methods were combined to contribute to the following section, our conceptual mapping (Fig. 3) and the ultimate synthesis of implications (section 5). We followed a multi-method state-of-the-art review process due to the future orientated nature of our research question and the need for comparison across broad (structured or systematised) and more specific (traditional) literatures (Grant and Booth, 2009). Inspiration was drawn from various innovation management literature review methodologies (Adams et al., 2006; Bowen et al., 2010; Medema et al., 2014).

3. The digitalisation of agricultural innovation systems

Digitalisation refers to the growth in human-computer or human-information and communication technologies (ICT) interaction (Billon

[2] This figure was updated on 14th October 2019 with title, keyword and abstracts queried for 'digital* OR smart OR precision' AND 'agricultur* OR farm*' AND 'institution* OR governance'. Partial year 2019 not included. Search contained all Scopus journal articles published or in press but will likely alter somewhat due to pagination updates over time.

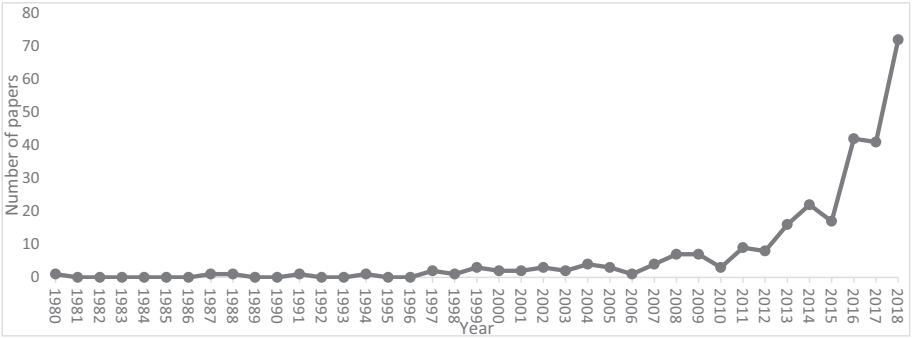

Fig. 1. Scopus listed papers in digital agricultural governance search query.

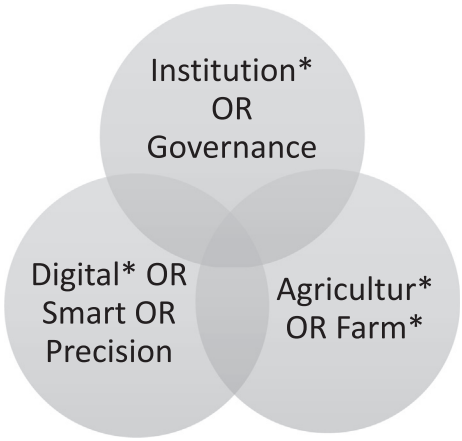

Fig. 2. Intersection of three structured literature review term categories.

dominant individuals, organisations, practices, and technologies both emerging and ceasing to exist, being by-passed or re-designed (Hueske et al., 2015; Leonard et al., 2017). This digital agricultural future has previously been referred to as agriculture 4.0 (Rose and Chilvers, 2018).

Agricultural innovation system theorisation recognises that innovation is more than simply the adoption of new technologies; it involves the co-evolution of technologies, societies, economies and institutions (Klerkx et al., 2012). Underpinning the study of agricultural innovation systems is an understanding that there is a relationship between the context of agricultural systems and the likely success, failure or otherwise of any given innovation (Schut et al., 2015). In this instance, innovation refers to something new, whether that be a product, process, practice or relationship (Turner et al., 2017). Agricultural innovation system conceptualisation offers a broad portfolio of research approaches depending on the complexity of the problem being addressed, stakeholders involved, and existing institutional settings. Al-

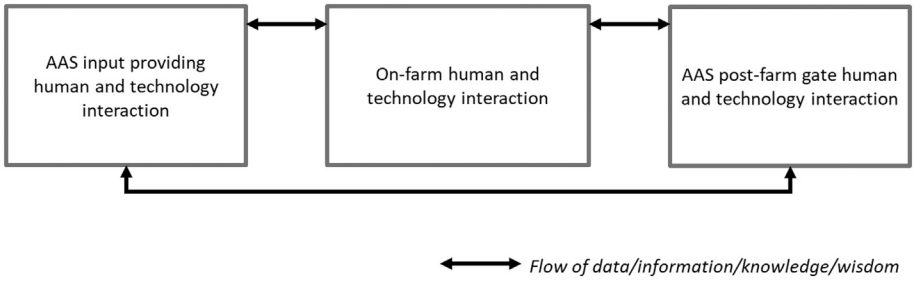

Fig. 3. Digitalisation of the agricultural knowledge and advice network - data, information, knowledge and wisdom feedbacks through agricultural advisory service (AAS) stakeholders and on-farm actors.

et al., 2010). Digitalisation differs from digitisation, which more specifically means to change a component part from analogue to digital (Preston and Allmand, 2001). The digitalisation of agriculture involves the development, adoption and iteration of digital technologies in the agricultural sector; what has been referred to as both digital agriculture (preferred in Australia and New Zealand) or smart farming (preferred in the European Union) in different spatial contexts (Robertson et al., 2016; Shepherd et al., 2018; Wolfert et al., 2017). The most often-cited impacts of digitalisation in agriculture tend to refer to precision agricultural technologies that broadly reduce input costs and/or increase yield or sustainability values (Aiello et al., 2019; Eastwood et al., 2019b; Lindblom et al., 2017).

Significant changes in agricultural systems are anticipated because of the convergence of new digital technologies, including, for example, real-time monitoring through sensors, big data, the Internet of Things, machine learning and cloud computing (Bramley and Ouzman, 2018; Wolfert et al., 2017). In some cases, this may lead to digital disruption, which is a term used to denote significant change in a system, with

ternative incarnations of an agricultural innovation systemic approach involve agricultural knowledge and information (or innovation) systems (Knierim et al., 2015; Rijswijk et al., 2019).[3]

Knowledge and advice networks are critical in terms of diffusing specific innovations through agricultural innovation systems. These networks circulate and situate knowledge, turning raw data and information into tacit knowledge and advice, to both reshape individual thinking and subsequently relationships with environments (Amitrano et al., 2017; Eastwood et al., 2017a; Nyasimi et al., 2017). Both private and public advisors can play an intermediary role in transferring knowledge to farmers through advisory services (Nettle et al., 2018). In the European context, the diverse range of knowledge transmission processes, for example an advisor facilitating management or practice change on-farm, have been referred to as agricultural advisory services

[3] For more information on developments in terminology, Klerkx et al. (2012) examine the evolution of agricultural innovation systems in relation to understanding agricultural systems and key enablers for innovation in great depth.

(Knierim et al., 2017)

A widespread shift is underway internationally with recognition of the importance of considering the process of innovation in agricultural research projects (Hall et al., 2006). From the one-dimensional technology transfer knowledge supply chain model whereby data is turned to information which is used to create knowledge that can be applied (Janssen et al., 2017) toward a co-innovative and networked approach that has been explicitly called for in the next 3–5 years in Australia (Ernst & Young, 2019). The addition of human computer interaction in, and between, each node of the agricultural knowledge and advice network is visualised in Fig. 3. Similarly, design thinking in the agricultural space could provide new impetus to foresight human computer interactions to increase sustainability values (Penzenstadler et al., 2014).

These developments build on existing research to conceptualise change in Australian agricultural knowledge and advice networks (Paschen et al., 2017) as being an industry-based component of a societal transition toward digital enlightenment (Helbing et al., 2019). Instead of concerns regarding *if* agricultural advisory services will be able to be replaced to fill service gaps, it may be possible for digitally disruptive technologies to subsume some of the traditionally human labour nodes in the agricultural knowledge and advice network. For example, fully autonomous farms being managed robotically (OECD, 2018; Oluboyede, 2017) and agricultural block chain technologies (Xie et al., 2017) are already being trialled to replace traditional farmers and financial intermediaries. Various digital technologies will continue to improve the ability of existing (and new) agricultural advisory services to provide value to clients in ever more accurate and efficient ways (Prager et al., 2016). Existing trends presented in the following literature review (see also Supplementary data) highlight the increasingly connected and transparent nature of agricultural knowledge and advice networks in the context of digitalisation. This socio-technical transition has been labelled the digitalisation of agricultural innovation systems (Fielke et al., 2019).

4. Major trends in agricultural advisory services in Australia

Having contextualised the key concepts and framings of the digitalisation of agricultural systems above, in this section we present a synopsis of the major trends influencing agricultural knowledge and advice networks. Our snowball literature review points to five major influential trends, namely: (i) diversification of information seeking behaviours and knowledge production processes by actors in agriculture; (ii) the increasing specialisation of decision-making expertise within complex advice networks; (iii) the privatisation of advice; (iv) the commodification of agricultural data; and, (v) the emergence of novel supply and service gaps in the system. These trends, their constituent sub-trends and key sources are presented in Table 1.

It is useful to consider how these broader trends (Table 1) relate to sub-groups or types of actors in the context of a specific national case, for example Australian agricultural knowledge and advice networks. In the remainder of this section, following Knierim et al. (2017) we describe how these changes are intersecting with private, non-government organisation, farmer-based, public research and education and public authority agricultural advisory services in Australia, with a focus on the roles and functions of these different advisory services. Overarching inclusion of more socio-ethical 'design' considerations regarding technological development in agriculture has the potential to alleviate the adoption failures of experiments such as a variety of scientifically-valid decision support systems (Rose et al., 2018). Including users and agricultural advisory service stakeholders in the process of design can help to maximise the value catalysed by such tool investment (Ditzler et al., 2018; Eastwood et al., 2019b).

4.1. Private agricultural advisory services

Within the context of privatisation and deregulation, private agricultural advisory services are now a key component of the Australian agricultural knowledge and advice network. Private agricultural advisory services range from sole operator consultants (e.g., self-employed agronomist consultants) through to large agri-business companies (e.g., re-sellers of fertilizer or other inputs). Importantly, many private advisors were trained and employed as State Government extension officers before the restructuring of Australian government institutions led to these individuals finding employment elsewhere or starting their own consulting businesses (Nettle et al., 2013). As this generation of publicly-trained extension officers retire, there has been increasing concerns regarding where the next generation of private agricultural advisory service employees might come from – so-called 'service gaps' (Nettle, 2017; Paschen et al., 2017). Farmers' perceptions of the value of fee-for-service advice is also variable due to the cultural legacy and expectations surrounding previous public-funded extension influencing expectations and advisor identities (Nettle et al., 2018). It is also important to consider the implications of private agricultural advisory services in terms of intellectual ownership. For example, knowledge accrued tacitly provides explicit transactional value in this form of agricultural advisory service.

4.2. NGO agricultural advisory services

Non-government organisation (NGO) agricultural advisory services include actors that are neither private nor public and tend to act as issue-based bodies in Australia. While historically NGO agricultural advisory services have not been a major influence on the Australian agricultural knowledge and advice network, there are examples where NGO agricultural advisory services are increasingly relevant. Issues of animal (livestock) welfare, property rights, environmental degradation, and genetic modification all have representative NGOs that influence, both directly and indirectly, agricultural practices and values. Arguably, in the Australian agricultural knowledge and advice network, this type of advisory service may be considered the least influential of all five agricultural advisory service categories. However, they still play a critical role. For example, a NGO agricultural advisory service recently released private information regarding farm locations on the internet via a spatial interface (Aussie Farms, 2019). The subsequent response from one farmer-based agricultural advisory service has also indicated that NGO agricultural advisory services are likely to increasingly challenge agricultural norms as we move into the digital age (National Farmers Federation, 2019).

4.3. Farmer-based agricultural advisory services

At the industry level, ten of the Rural Research and Development Corporations (RDCs) are levy-funded, with a further five existing as publicly-funded entities, although in reality the line between industry and public funding usually involves significant co-investment (Australian Government, 2017). Broader trends of deregulation and privatisation have resulted in farmer-based agricultural advisory services needing to provide an explicit value proposition to farmers/agricultural stakeholders, to justify the time, effort and cost (i.e. levy payment) involved in being a member. For example 'governing through the community' is argued to be one responsibility of Landcare groups that can be granted project funding to maximise their organisations ownership while simultaneously reducing the burden of public good works on formal governance institutions (Wang et al., 2017).

4.4. Public research and education agricultural advisory services

Australian public research and education agricultural advisory services are fragmented across universities, state and Federal Government

Table 1
Major and sub trends in agricultural knowledge and advice networks.

Major trends	Sub-trends	Source/s
Diversification of information seeking and knowledge production	Continued one-to-one interaction, farmer-to-private agricultural advisory services although some farm types may not be serviced (e.g., smaller farms and those with reduced ability to pay for services)	Labarthe and Laurent (2013); Prager et al. (2016)
	One-to-many interactions increasingly conditioned on other trusted agricultural advisory services relationships	Sutherland et al. (2013)
	Information-seeking behaviours move toward global sources of information	Prager et al. (2017)
	Farmer-based agricultural advisory services continue to be important for knowledge co-creation/experimentation	Eastwood et al. (2017b)
	Group-based co-learning service delivery supported by on-line interaction – particularly in public agricultural advisory services – co-production of knowledge between farmers and advisor's a prerequisite for developing solutions that are relevant/consistent with farmers' contexts/objectives and building/maintaining mutual trust	Klerkx and Jansen (2010); Rijswijk and Brazendale (2017)
	Farmers having limited capacity for new information, knowledge, management changes – varying prioritisation of advisory services depending on values and farm type – alteration of practice/management will have implications for tacit knowledge of the 'farm' and agri-'culture'	Nettle et al. (2018)
Specialisation within complex networks and decisions	Professionalisation of agriculture	Murphy et al. (2013)
	Recognition of increasing complexity of multiple rural land management objectives	Eastwood et al. (2017b); Phillipson et al. (2016)
	Increasing data/technical intensity of decision making	Janssen et al. (2017); Nettle (2017); Nettle et al. (2018)
	Farmers and advisors face identity and world view changes	Eastwood et al. (2017a); Nettle (2017)
	Greater specialisation and diversification of service providers – results in varying quality of services and clients targeted	Knierim et al. (2017)
	Increasing data-based as opposed to process-based decision making	Lioutas et al. (2019)
Privatisation of advice	Individual profit motive dominates rationality of Australian agricultural advisory services with fragmentation due to market and technology-based specialisation	Fielke and Wilson (2017); Eastwood et al. (2017b); Paschen et al. (2017)
	Recognition of market failures regarding public good and productivity outcomes – decreasing productivity growth rates	Hunt et al. (2014); Meadows et al. (2014)
	Advisors want to participate in RD&E but farmers and public agricultural advisory services are unsure of roles	Keogh and Julian (2013); Nettle (2017); Nettle et al. (2018)
	Advice must provide/add value and maintain legitimacy – co-benefits of advice (information, networks, technology) must be evident and advisors are now an input cost – as a result advice also needs to fit into/guide farm business plan/strategy	Robertson et al. (2016)
Emerging supply/service gaps and new demands	Public agricultural advisory services unable to economically support agricultural sector beyond market failures	Hunt et al. (2014); Robertson et al. (2016)
	Increasingly demanding consumers, private organisations in the value chain, civil society and NGOs, and governments	Fielke and Bardsley (2015); Murphy et al. (2013)
	Counter-trend of niche high-quality production to capture ethical values	Fielke and Bardsley (2013)
	Counter-trend of niche high-quality production to capture ethical values	Fielke and Bardsley (2013)
Commodification of agricultural data	Culture of intellectual ownership	Klerkx and Nettle (2013)
	Lack of institutional support for coordination of responsibilities of private governance of natural resources	Rijswijk et al. (2018); Taylor and Van Grieken (2015); Wang et al. (2017)
	Internationally, vertical integration of dominant players in the knowledge supply chain – data through to analytics	Bronson (2018); Carolan (2018)
	Data privacy/management debates about who benefits in the agricultural space – open, closed, public, private etc	Wiseman et al. (2018); Wolfert et al. (2017)

research departments, RDCs, and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Momentum from a reduction in publicly-funded extension, the shift to more privatised agricultural advisory services since the 1980s, and a lack of appropriate formal education and training options for agricultural stakeholders (including farmers and advisors) is noted to be of concern in recent research on the state of Australian education and extension services (Fielke and Bardsley, 2014; Nettle, 2017). Public research is geared toward mission-based programmes that aim to maximise productivity and/or minimise the negative externalities of agricultural practice to provide appropriate return on research investment (Gaunand et al., 2015; Thorburn et al., 2011). Therefore, the role of digitalisation to facilitate further (or the next round of) Australian agricultural productivity gains, and in doing so remaining internationally competitive, is increasingly the focus of research and development efforts in this space (Barry et al., 2017; CSIRO, 2017; Ernst & Young, 2019).

4.5. Public authority agricultural advisory services

Public authority agricultural advisory services have decreased in terms of influence since the deregulation of the Australian agricultural sector, although public agricultural advisory services still retain responsibility for functions such as biosecurity management, the distribution of funding and assistance programmes (e.g. drought assistance), and related natural resource management (Australian Government, 2011). In some cases, however, these public good functions are also being questioned. For example, it has been reported that biosecurity (the prevention of incursions) is of benefit primarily to the agricultural sector and therefore agricultural industry stakeholders should be responsible for management costs (Fielke and Wilson, 2017). The nature of public authorities providing agricultural advice could be conceptualised as beginning to align with the European notion of co-innovation, through the 'golden triangle' of industry (farmer-based, private and NGO agricultural advisory services), government (public authorities), and knowledge institutes (public research and education) (Robertson et al., 2016).

5. Synthesis of implications: connectivity, transparency and governance

By considering the structured review findings, current settings and developments relevant to agricultural knowledge and advice networks,

future scenarios can be imagined. Importantly, this paper neither advocates for, nor aims to, accurately predict trends in the themes discussed. Rather, in undertaking such an analysis and looking at the implications of three key trends here it is possible to consider the implications of digitalisation on Australian – and more generally international – agricultural knowledge and advice networks and agricultural innovation systems (Arts et al., 2011; Darnell et al., 2018). The structured review overview (see appendix A and Supplementary data) was unable to fully capture the nuances of the international digitalisation of agricultural innovation systems due to the speed at which digital developments are taking place (Fielke et al., 2019). However, the preceding analysis of the two different review formats allow us to synthesise an answer to the primary research question: how could existing trends in agricultural advisory service structure and potential digital developments influence the performance of agricultural knowledge and advice networks?

For brevity, the key themes pulled out from the method regarding the implications of digitalisation on agricultural innovation systems can be summarised as: increasing *transparency* and *connectivity* associated with agricultural production practices and associated implications for *governance*. Further detail on potential digitalisation implications for Australian agricultural knowledge and advice networks can be found in Appendix B, including optimistic future scenarios taken from examples in extant literature. We focus here, however, on themes of broader international relevance and provide relevant future research questions that would frame interrogation into the changing nature of each of these themes in the digital agricultural system domain. The synthesis narrative was built from the overall results of our state-of-the-art review (combining analysis of Fig. 3, Table 1, and all appendices/supplementary data).

5.1. Connectivity

Connectivity of humans and technologies in agricultural knowledge and advice networks and associated value exchange will likely continue to increase in novel ways. As Fig. 3 indicates, the connections and feedbacks of data, information, knowledge and wisdom amongst actors in agricultural systems will likely move from the value chain analogy of decades passed to a value exchange process. This is pre-empted by increasingly recognised farmer and advisor concerns and questions surrounding data access and sovereignty as we move into the digital age (Jakku et al., 2019; Lioutas et al., 2019; Regan, 2019; Rotz et al., 2019; Wiseman et al., 2019). Significantly, the current settings of Australian agricultural knowledge and advice networks involve interactions amongst and within various agricultural advisory service types, and some actors take on multiple agricultural advisory service roles at different times or when serving certain functions. Digital technologies are and will continue to be engaged with, to varying degrees, by human agricultural advisory service actors. The result will be increasing technologically mediated (on-line) social interaction - farmer-to-customer, farmer-to-farmer and farmer-to-advisor - that can support new online service provision business models (Lubell et al., 2014). This increasing connectivity – of digital devices and individuals as users – is likely to increase as machine learning allows technologies to more effectively communicate with both humans and other technological devices and actors (EU SCAR, 2015; Ministry of Defence, 2014; Penzenstadler et al., 2014). For example, advisor roles may begin to include technological intermediary design as applications ('apps') provide information in more palatable and timely formats – requiring evolving digital technical skills and associated adaption of tasks (Berthet et al., 2018). Increased technologically-driven decision-making (through real-time sensing, auto-bots and intuitive front ends) may become the basis for certain forms of advice and advisors willing to adapt into such a space (Eastwood et al., 2019a). Importantly, agricultural knowledge and advice networks will still be grounded by social relationships that are critical to the success of co-innovation and co-design approaches to agricultural technology development and therefore usefulness and adoption by the farming community, as explained in the context of carbon farming tools by Fleming et al. (2019). The importance of social ties will likely be tempered by spatial reality, with digitally mediated interactions when travel/transaction costs are prohibitive. The critical intrinsic value of relational social (face-to-face) interactions between and within governance, researcher, advisor, and farmer networks will increase as these relationships embody the different forms of social capital required to create future visions and negotiate data sharing arrangements and privacy outcomes (King et al., 2019).

While the transition to a more digitally-interconnected environment will involve significant infrastructure and transaction costs (in refining data accessibility and management to capture value), increasing technological capacity and networks of social capital should naturally provide new platforms for agricultural stakeholders to exploit (Lubell et al., 2014). Even digital deprivation, in terms of poor internet connectivity, reliability and speed, has been argued to be surmountable as digital agricultural technologies develop (Darnell et al., 2018). Private agricultural advisory services already use comprehensive and globally-interconnected digital systems/platforms. Co-operative data sharing arrangements are also increasingly questioning existing institutional legacies in agricultural industries in Australia and globally (Sutherland et al., 2013; Walter et al., 2017). How institutional change associated with technological development is guided in different places will determine the agri-food priorities of perhaps increasingly diverse but virtually connected regions, communities, agri-businesses and value exchange stakeholders (Wolfert et al., 2017).

Three questions for future research:

- How can digital agricultural technology users recognise those who create value and increase incentives to further mediate exchange?
- What new business models might emerge to take advantage of these exchanges?
- What are the future intermediary tasks (that both humans and machines might do) that agriculture 4.0 will catalyse?

5.2. Transparency

Transparency of agricultural practices and informational interaction between farmers, advisors, agri-businesses, consumers and regulators will drive and be driven by growing connectivity, also indicated by exchanges in Fig. 3, but also need to consider broader public opinion (Lush, 2018). Trust values embedded in relationships between farmers themselves (Sligo and Massey, 2007) and interactions with technologies are likely to change over time as digital information flows become ubiquitous – increasing transparency (Kelton et al., 2008). Improved understanding of the implications of trust as agricultural knowledge and advice networks digitalise will be critical in determining the place of agricultural intermediaries (either human or technological) to influence agricultural innovation into the future (Bessant and Rush, 1995; Howells, 2006). Because of increasing connectivity, the transparency of interactions between technologies and humans is also likely to increase. Flows of data, information and analytics, along with the levels of trust or value placed in these components of knowledge exchange (Fig. 3), will shift as the pervasiveness of digital technologies increases (Wolfert et al., 2017). There are implications for agricultural advisory services as a result. For example, through social media, issue-based NGOs and consumers themselves, public reports can be made on events in real-time. Recent examples of increasing societal transparency include animal welfare concerns (along with swift institutional responses) (Aussie Farms, 2019; National Farmers Federation, 2019), the boycotting of the consumption of certain brands or products on ethical grounds, the alignment of private interests with ethical initiatives (Busch, 2011), and the exposure of privacy concerns surrounding the third party use of data through Facebook (Duffy, 2018). As the lines between digital

technology use, consumption and data provision blur, it will become increasingly hard for business models built on secrecy, illusion or rent-seeking to go unnoticed. The trend toward privatisation of agricultural advice will likely see a shift in advisor identity to include private governance and certification surveillance – advisors may also be required to maintain sensor equipment to satisfy quality and practice standards of agri-food value exchange (Eastwood et al., 2019a). As Wiseman et al. (2018), p. 76) explain after discussing examples of international data management policy developments:

> There is a need to shift the narrative away from ownership… to clarify the goals of good data management in order to achieve a more open culture of better control, access and benefit-sharing [transparency] of Australian agricultural data.

The increasing quantity of data collected, along with gains in analytical efficiency through machine learning will increase surveillance power in both public and private senses – digital devices in homes and autonomous vehicles have already been used to provide evidence in legal proceedings in the United States of America (Stilgoe, 2018; Volwes and Story Carter, 2018). Economic value adding will become increasingly dependent on socio-environmental stewardship with premiums on offer for unique production and increased digital surveillance of agricultural practices and produce provenance (Regan, 2019). Similarly, big data analytics and improved design interfaces have the potential to make technical decision-making simpler, more timely and better aligned with tacit agricultural knowledge (Fleming et al., 2018). Farmers, agricultural advisory services and agricultural industry stakeholders should consider the implications for their practices in terms of how they might turn 'trusted' information into tacit knowledge/wisdom in the future (Fisher, 2013) and the increasing right of society – through NGO agricultural advisory services and social media – to influence on-farm production practices (Lush, 2018).

Three questions for future research:

- What does responsible stewardship of agricultural data assets look like and how might it be facilitated to meet societal goals as opposed to purely private interests?
- How do agricultural stakeholders determine who to trust in the digital age, what combinations of social and digital capital are optimal?
- What can agricultural sector stakeholders do to protect themselves from 'fake news' and false propaganda, maintain cyber security, and collaborate with digital natives who have a technical and informational advantage?

5.3. Governance

Finally, there are likely to be challenges balancing the priorities of various agricultural stakeholders asagricultural innovation systems digitalise. These digital agricultural system challenges will require trade-offs to be made between public and private organisations and their individual representatives (Carolan, 2018; Regan, 2019). Socio-ethical considerations when developing digital technologies to meet public and private goals in the agricultural sector have been explicitly considered for decades (Wolf and Buttel, 1996; Wolf et al., 2001). Past lessons in agricultural decision support system development indicate it will not be enough to electronically simulate decisions without consideration of the agri-social systems that land managers and agricultural advisory services are a part of (Botha et al., 2017; Fielke et al., 2018; Klerkx et al., 2017; Vereijssen et al., 2017). Therefore, it is important that technological optimism driving digital tool development is tempered by the social realities of managing innovation benefits through appropriate governance (Fleming et al., 2018).

As mentioned earlier, existing research points to the increasing privatisation of agricultural advisory services and the restructuring of agricultural research and extension away from public good funders (Knierim et al., 2017; Nettle et al., 2018; Paschen et al., 2017; Prager et al., 2016). This trend is likely to continue, particularly in agriculturally-competitive and export-oriented nations. As such, formal governance institutions act as market facilitators, although this leaves public authority and public research and education agricultural advisory services in a position where traditional technology transfer and monitoring/surveillance responsibilities become much broader. A complex layering of private, quasi-public, and explicitly public governance is unlikely to be simplified. The transition to a digital agricultural future has significant implications regarding the governance of data ownership, curation, analysis, and the negotiation of values, with the economically and politically powerful likely able to determine the manner in which digital technologies are developed (Jakku et al., 2019; Newell and Taylor, 2017). In support of research examining the role of law in keeping up with technological development, it seems more efficient and relevant to regulate the human interactions with digital technologies, as opposed to the technologies themselves (Wiseman et al., 2018).

By shifting priorities of the state, neoliberalism has resulted in diverse and fragmented agricultural stakeholders, which has subsequently decreased individual political bargaining power against large private corporations whose inputs are relied upon. There are examples, however, of community-led multi-party governance underpinned by shared social principles (Oreszczyn et al., 2010; Taylor and Van Grieken, 2015). Digital technologies can provide a platform for the geographically diverse engagement of farmers with stakeholders across the supply chain. There is also increased impetus for data science to make information meaningful in a manner that is responsible (Rattenbury and Nafus, 2018) – anticipating outcomes, including diverse stakeholders, being responsive to change and reflexive in practice (Eastwood et al., 2019b). As such the framing of data is likely to become politically relevant such that some form of governance is required to monitor the representativeness, accuracy and security of the data that decisions are based on. For example, negotiation around the 'terms of use' of digital agricultural technologies, both formally and informally, provides some space to determine the rules of the game (Leonard et al., 2017; Wiseman, 2016).

Three questions for future research:

- How will different jurisdictions (countries, regions) determine their digital agricultural priorities – domestic or international markets, technology or culture, people or planet, open or closed, collaboration or competition?
- What does socio-ethically responsible enforcement of digital agricultural policies mean, on the continuum from state agricultural surveillance through to self-reported and industry led monitoring?
- How will conflicting principles of scientific disciplinary integration through digital agricultural technology development be staged out?

6. Conclusions and limitations

By framing agricultural knowledge and advice networks within the broader agricultural innovation system, we were able to report on the current state-of-the-art in relation to the coming digital transformation of these systems. We examined the literature in a structured manner to understand trends and framing of digitalisation as it relates to agricultural governance and institutional change. We then implemented a traditional snowball literature review to better understand the implications of digitalisation on agricultural advisory services moving forward (Knierim et al., 2017). It was found the outcomes of digitalisation would likely involve increasing connectivity and transparency (Fig. 3), along with the diversification and ongoing re-structuring of agricultural governance (Darnell et al., 2018; Nettle et al., 2018; Wiseman et al., 2018). When reflecting on our findings, limitations and gaps for future analytical exploration should be considered. Most importantly, the secondary analysis of the state-of-the-art was ultimately

the result of author judgement and interpretation. We attempted to minimise bias by utilising a structured and collaborative review process initially, although the broader inclusion of literature was required to ground trends of relevance. Social research can also never be completely value free. In focusing on trend themes, we aimed to guide the reader as opposed to force certain scenarios, for example by suggesting specific technological adoption, policy outcomes, or forms of institutional change.

The review process does raise recommendations for future analytical methods, however, with foresight (looking 5–10 years into the future such as that conducted in relation European agricultural innovation systems (EU SCAR, 2015)) and far sight (looking 10–30 years into the future) providing important time periods to consider moving forward. Thinking beyond 5 years into the future would also allow for a more explicit focus on broader societal transformation processes – through social learning, governance and cultural change – rather than specific temporarily dominant technological developments regarding current modes of agricultural operation. This forward-thinking approach would also provide space to imagine convergent transformation across industries, for example in energy (carbon considerate and decentralised smart grids), transport (autonomous vehicles connected via cyber-physical systems), and communication (online and harvested for data) (Rifkin, 2013). Further extrapolation does, however, result in decreasing predictability, as transformation more broadly will both influence and be influenced by agricultural innovation system change over time.

Acknowledgements

Many colleagues have also been influential in building the ideas presented here. The authors would also like to thank the anonymous reviewers, Liz Hobman, Maria Vilas, Aysha Fleming, and Cara Stitzlein for their input. We also acknowledge funding from the CSIRO Digiscape Future Science Platform that allowed this work to be undertaken. Finally, we are grateful for collegial discussions with Kelly Rijswijk, Laurens Klerkx, James Turner, Martijn Mooij and Peter Thorburn that contributed to our thinking in this space.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Link to Scopus result of 276 papers of which abstracts were reviewed for suitability - Results accurate as of 14th October 2019 for full year 2018 and prior.

https://www.scopus.com/results/results.uri?sort=plf-f&src=s&nlo=&nlr=&nls=&sid=7fbba8365d3ef7b9a3a49ecbad008d46&sot=a&sdt=cl&cluster=scopubyr%2c%222020%22%2cf%2c%222019%22%2cf&sl=156&s=TITLE-ABS-KEY%28%22precision%22+OR+%22digital*%22+OR+%22smart%22+AND+%22agricultur*%22+OR+%22farm*%22+AND+%22institution*%22+OR+%22governance%22%29++AND+%28DOCTYPE%28+ar+%29+OR+PUBSTAGE%28+aip+%29+%29&origin=resultslist&zone=leftSideBar&editSaveSearch=&txGid=9ac8b6bc92d324f81fd9a964663775d0

Appendix B. Australian agricultural knowledge and advice network trends including potential digitalisation implications in an optimistic scenario

Individuals involved (key theme of relevance)	Dominant trends	Sub-trends	Sources	Potential digitalisation visions
Farmers (Transparency)	Increasing density and complexity of networks of farmers and advisors	Recognition of increasing complexity of multiple rural land management objectives	Eastwood et al. (2017b)	Machine learning is utilised to better model complex systems in a manner such that targeted users can digest and trust the results of Big data analytics and improved design interfaces make technical decision-making simple, timely and more appropriately aligned with tacit agricultural knowledge
		Increasing data/technical intensity of decision making	Janssen et al. (2017); Nettle (2017)	
		Farmers and advisors face identity and world view changes	Nettle et al. (2018)	Increasing technologically mediated (on-line) social interaction, farmer-to-customer, farmer-to-farmer and farmer-to-advisor
		Greater specialisation and diversification of service providers	Eastwood et al. (2017a); Nettle (2017)	Increased technologically-driven decision-making (through real-time sensing, auto-bots and intuitive front ends) becomes the basis for advice
Private advisors (Connectivity)	Private advisors are increasingly influential in terms of both advice and surveillance to maintain economic value	Advisory service fragmentation through market and technology-based specialisation	Eastwood et al. (2017b); Paschen et al. (2017)	Advisors roles move to include technological intermediary designers as applications provide information in more acceptable formats – requiring evolving digital technical skills and associated adaption of tasks
		Recognition of market failures regarding public good and productivity outcomes – decreasing productivity growth rates	ABS (2018); Hunt et al. (2014); Meadows et al. (2014)	Further privatisation of the advisory services sees a shift in advisor identity to private governance and certification surveillance – advisors also maintain sensor equipment to satisfy quality and practice standards of agri-food supply chains
		Advisors want to participate in RD&E but farmers and public agricultural advisory services are unsure of roles	Keogh and Julian (2013); Nettle (2017)	Increasing technologically mediated (on-line) social interaction advisor-to-farmer, and advisor-to-advisor
Public advisors (Governance)	Strategic involvement and filling private supply gaps for public good	Public agricultural advisory services unable to economically support agricultural sector beyond market failures	Hunt et al. (2014); Robertson et al. (2016)	Cultural shift in public agricultural research, development and extension organisations to embrace socio-technical interaction through co-innovation and design principles
		Decline in number of farms and increasingly demanding consumers,	ABS (2018); Fielke and Bardsley	Public agricultural research, development and extension becomes socio-digital in nature to address market

		private organisation, civil society and NGOs	(2015); Murphy et al. (2013)	failures – for example leading and participating in long-term strategic initiatives and maximising public goods via both person-to-person and online community interaction
		Counter-trend of niche high-quality production to capture ethical values	Fielke and Bardsley (2013)	Increasing technologically mediated (on-line) social interactions advisor-to-farmer and advisor-to-advisor support new online service provision business models
Policy makers (Governance)	Technologically-optimistic logic and decreasing agricultural influence	Individual profit motive dominates rationality of Australian agricultural knowledge and advice network	Fielke and Wilson (2017); Klerkx and Nettle (2013)	Economic profit becomes increasingly dependent on socio-environmental stewardship – premiums on offer for unique production – increased digital surveillance of agricultural practice
		Lack of institutional support for cooperation and shift of responsibility toward private governance of natural resources	Taylor and Van Grieken (2015); Wang et al. (2017)	Social (face-to-face) interactions drive multi-party engagement with research, development and extension actors through design feedback loops that are then supported digitally when travel/transaction costs are prohibitive – maintenance of agricultural relevance economically and culturally
		Increasing data privacy/management debates in the agricultural space – open, closed, public, private etc	Wiseman et al. (2018)	Critical intrinsic value of social (face-to-face) interaction between and within governance, researcher, advisor, and farmer networks increases. These relationships embody the social capital required to create future visions and negotiate acceptable data sharing/privacy outcomes

Appendix C. Supplementary data

Supplementary material: Appendix C Coding matrix of 28 papers read in full to situate perspectives of authors on digital agricultural technology and institutions/governance - lag time may have prevented in depth examination of all the relevant papers from appendix A if they were online but not paginated or allocated to a specific year when analysis took place. Supplementary data to this article can be found online at doi: https://doi.org/10.1016/j.agsy.2019.102763.

References

EU SCAR, 2015. Agricultural Knowledge and Innovation Systems Towards the Future – a Foresight Paper. European Union, Brussels.

ABS, 2018. Agricultural Commodities. Australia - Past and present releases. http://www.abs.gov.au/AUSSTATS/abs@.nsf/second+level+view?ReadForm&prodno=7121.0&viewtitle=Agricultural%20Commodities,%20Australia~2016-17~Latest~21/05/2018&&tabname=Past%20Future%20Issues&prodno=7121.0&issue=2016-17&num=&view.

Adams, R., Bessant, J., Phelps, R., 2006. Innovation management measurement: a review. Int. J. Manag. Rev. 8 (1), 21–47.

Aiello, G., Giovino, I., Vallone, M., Catania, P., Argento, A., 2019. Online. A decision support system based on multisensor data fusion for sustainable greenhouse management. J. Clean. Prod. 172, 4057–4065. https://doi.org/10.1016/j.jclepro.2017.02.197.

Amitrano, C.C., Coppola, M., Tregua, M., Bifulco, F., 2017. Knowledge Sharing in Innovation Ecosystems: A Focus on Functional Food Industry. Int. J. Innov. Technol. Manag. 14 (5) Art. 1750030.

Arts, J.W.C., Frambach, R.T., Bijmolt, T.H.A., 2011. Generalizations on consumer innovation adoption: a meta-analysis on drivers of intention and behavior. Int. J. Res. Mark. 28 (2), 134–144.

Australian Government, 2011. The Agricultural Resource Management Survey. Australian Government, Canberra.

Australian Government, 2017. Rural Research and Development Corporations. http://www.agriculture.gov.au/ag-farm-food/innovation/research_and_development_corporations_and_companies.

Ayre, M., Mc Collum, V., Waters, W., Samson, P., Curro, A., Nettle, R., Paschen, J.-A., King, B., Reichelt, N., 2019. Online. Supporting and practising digital innovation with advisers in smart farming. NJAS – Wagenin. J. Life Sci. 90–91, 100302. https://doi.org/10.1016/j.njas.2019.05.001.

Baker, C., 2018. The nation-building state retreats: an Australian case study in the changing role of the state. J. Rural. Stud. 62, 146–155.

Barry, S., Darnell, R., Grundy, M., Moore, A., Robertson, M., Brown, J., Gaire, R., George, A., 2017. Precision to Decision – Current and Future State of Agricultural Data for Digital Agriculture in Australia. CSIRO, Australia.

Berthet, E.T., Hickey, G.M., Klerkx, L., 2018. Opening design and innovation processes in agriculture: insights from design and management sciences and future directions. Agric. Syst. 165, 111–115.

Bessant, J., Rush, H., 1995. Building bridges for innovation: the role of consultants in technology transfer. Res. policy 24 (1), 97–114.

Billon, M., Lera-Lopez, F., Marco, R., 2010. Differences in digitalization levels: a multivariate analysis studying the global digital divide. Rev. World Econ. 146 (1), 39–73.

Botha, N., Turner, J.A., Fielke, S., Klerkx, L., 2017. Using a co-innovation approach to support innovation and learning: cross-cutting observations from different settings and emergent issues. Outlook on Agric. 46 (2), 87–91.

Bowen, F., Newenham-Kahindi, A., Herremans, I., 2010. When suits meet roots: the antecedents and consequences of community engagement strategy. J. Bus. Ethics 95 (2), 297–318.

Bramley, R.G.V., Ouzman, J., 2018. Farmer attitudes to the use of sensors and automation in fertilizer decision - making: nitrogen fertilization in the Australian grains sector. Precis. Agric. https://doi.org/10.1007/s11119-018-9589-y.

Bronson, K., 2018. Smart farming: including rights holders for responsible agricultural innovation. Technol. Innov. Manag. Rev. 8 (2), 7.

Busch, L., 2011. The private governance of food: equitable exchange or bizarre bazaar? Agric. Hum. Values 28 (3), 345–352.

Carolan, M., 2018. "Smart" farming techniques as political ontology: access, sovereignty and the performance of neoliberal and not-so-neoliberal worlds. Sociol. Rural. https://doi.org/10.1111/soru.12202.

CSIRO, 2017. The Digiscape Future Science Platform. https://research.csiro.au/digiscape/.

Darnell, R., Robertson, M., Brown, J., Moore, A., Barry, S., Bramley, R., Grundy, M., George, A., 2018. The current and future state of Australian agricultural data. Farm Policy J. 15 (1), 41–49.

Ditzler, L., Klerkx, L., Chan-Dentoni, J., Posthumus, H., Krupnik, T.J., Ridaura, S.L., Andersson, J.A., Baudron, F., Groot, J.C.J., 2018. Affordances of agricultural systems analysis tools: a review and framework to enhance tool design and implementation. Agric. Syst. 164, 20–30.

Duffy, C., 2018. Facebook Is The Real Over-Sharer And Mark Zuckerberg Will Have A Tough Time Telling Congress Why. http://www.abc.net.au/news/2018-04-10/facebook-is-real-over-sharer-zuckerberg-faces-congress/9635522.

Dufva, T., Dufva, M., 2019. Online. Grasping the future of the digital society. Futures 107, 17–28. https://doi.org/10.1016/j.futures.2018.11.001.

Eastwood, C., Klerkx, L., Nettle, R., 2017a. Dynamics and distribution of public and private research and extension roles for technological innovation and diffusion: case studies of the implementation and adaptation of precision farming technologies. J. Rural. Stud. 49, 1–12.

Eastwood, C.R., Dela Rue, B.T., Gray, D.I., 2017b. Using a 'network of practice' approach to match grazing decision-support system design with farmer practice. Anim. Prod. Sci. 57 (7), 1536–1542.

Eastwood, C., Ayre, M., Nettle, R., Dela Rue, B., 2019a. Online-a. making sense in the cloud: farm advisory services in a smart farming future. NJAS – Wagenin. J. Life Sci. 90–91, 100298. https://doi.org/10.1016/j.njas.2019.04.004.

Eastwood, C., Klerkx, L., Ayre, M., Dela Rue, B.T., 2019b. Online-b. managing socio-ethical challenges in the development of smart farming: from a fragmented to a comprehensive approach for responsible research and innovation. J. Agric. Environ. Ethics 32 (5–6), 741–768. https://doi.org/10.1007/s10806-017-9704-5.

Farms, Aussie, 2019. The Aussie Farms Map. https://map.aussiefarms.org.au/.

Federation, National Farmers, 2019. Farmers Fight Back In Face Of Radical Anti-Farm Group Intimidation. https://www.nff.org.au/read/6262/farmers-fight-back-in-face-of.html.

Fielke, S., Bardsley, D., 2013. South Australian farmers' markets: tools for enhancing the multifunctionality of Australian agriculture. GeoJournal 78 (5), 759–776.

Fielke, S.J., Bardsley, D.K., 2014. The importance of farmer education in South Australia. Land Use Policy 39, 301–312.

Fielke, S., Bardsley, D., 2015. A brief political history of South Australian agriculture. Rural. Hist. 26 (1), 101–125.

Fielke, S., Wilson, G., 2017. Multifunctional intervention and market rationality in

agricultural governance: a comparative study of England and South Australia. GeoJournal 82 (5), 1067–1083.
Fielke, S.J., Botha, N., Reid, J., Gray, D., Blackett, P., Park, N., Williams, T., 2018. Lessons for co-innovation in agricultural innovation systems: a multiple case study analysis and a conceptual model. J. Agric. Educ. Ext. 24 (1), 9–27.
Fielke, S., Garrard, R., Jakku, E., Fleming, A., Wiseman, L., Taylor, B., 2019. Online. Conceptualising the DAIS: implications of the 'digitalisation of agricultural innovation systems' on technology and policy at multiple levels. NJAS – Wagenin. J. Life Sci. 32 (5–6), 741–768. https://doi.org/10.1016/j.njas.2019.04.002.
Fisher, R., 2013. 'A gentleman's handshake': the role of social capital and trust in transforming information into usable knowledge. J. Rural. Stud. 31, 13–22.
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. Agron. Sustain. Dev. 38 (3) Art. 24.
Fleming, A., Stitzlein, C., Jakku, E., Fielke, S., 2019. Missed opportunity? Framing actions around co-benefits for carbon mitigation in Australian agriculture. Land Use Policy 85, 230–238.
Gaunand, A., Hocdé, A., Lemarié, S., Matt, M., Turckheim, E., 2015. How does public agricultural research impact society? A characterization of various patterns. Res. Policy 44 (4), 849–861.
Grant, M.J., Booth, A., 2009. A typology of reviews: an analysis of 14 review types and associated methodologies. Health Inf. Libr. Jo. 26 (2), 91–108.
Hall, A., Janssen, W., Pehu, E., Rajalahti, R., 2006. Enhancing Agricultural Innovation: How to Go beyond the Strengthening of Research Systems. World Bank, Washington D.C.
Helbing, D., Frey, B.S., Gigerenzer, G., Hafen, E., Hagner, M., Hofstetter, Y., Van Den Hoven, J., Zicari, R.V., Zwitter, A., 2019. Will democracy survive big data and artificial intelligence? In: Helbing, D. (Ed.), Towards Digital Enlightenment. Springer, Australia, pp. 73–98.
Ernst & Young, 2019. Agricultural innovation - A national approach to grow Australia's future. http://www.agriculture.gov.au/ag-farm-food/innovation/vision-for-agricultural-innovation.
Howells, J., 2006. Intermediation and the role of intermediaries in innovation. Res. policy 35 (5), 715–728.
Hueske, A.-K., Endrikat, J., Guenther, E., 2015. External environment, the innovating organization, and its individuals: a multilevel model for identifying innovation barriers accounting for social uncertainties. J. Eng. Technol. Manag. 35, 45–70.
Hunt, W., Birch, C., Vanclay, F., Coutts, J., 2014. Recommendations arising from an analysis of changes to the Australian agricultural research, development and extension system. Food Policy 44, 129–141.
Jakku, E., Taylor, B., Fleming, A., Mason, C., Fielke, S., Sounness, C., Thorburn, P., 2019. Online. "If they don't tell us what they do with it, why would we trust them?" trust, transparency and benefit-sharing in smart farming. NJAS – Wagenin. J. Life Sci. 90–91, 100285. https://doi.org/10.1016/j.njas.2018.11.002.
Janssen, S.J.C., Porter, C.H., Moore, A.D., Athanasiadis, I.N., Foster, I., Jones, J.W., Antle, J.M., 2017. Towards a new generation of agricultural system data, models and knowledge products: information and communication technology. Agric. Syst. 155, 200–212.
Kelton, K., Fleischmann, K.R., Wallace, W.A., 2008. Trust in digital information. J. Assoc. Inf. Sci. Technol. 59 (3), 363–374.
Keogh, M., Julian, C., 2013. Part 1: Background, literature and demographics of the Australian grain production sector. In: Optimising future extension systems in the Australian grains industry. Australian Farm Institute, Sydney.
King, B., Fielke, S., Bayne, K., Klerkx, L., Nettle, R., 2019. Navigating shades of social capital and trust to leverage opportunities for rural innovation. J. Rural. Stud. 68, 123–134.
Klerkx, L., Jansen, J., 2010. Building knowledge systems for sustainable agriculture: supporting private advisors to adequately address sustainable farm management in regular service contacts. Int. J. Agric. Sustain. 8 (3), 148–163.
Klerkx, L., Leeuwis, C., 2009. Establishment and embedding of innovation brokers at different innovation system levels: insights from the Dutch agricultural sector. Technol. Forecast. Soc. Chang. 76 (6), 849–860.
Klerkx, L., Nettle, R., 2013. Achievements and challenges of innovation co-production support initiatives in the Australian and Dutch dairy sectors: a comparative study. Food Policy 40 (1), 74–89.
Klerkx, L., van Mierlo, B., Leeuwis, C., 2012. Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions. In: Darnhofer, I., Gibbon, D., Dedieu, B. (Eds.), Farming Systems Research into the 21st Century: The New Dynamic. Springer, Netherlands, pp. 457–483.
Klerkx, L., Seuneke, P., de Wolf, P., Rossing, W.A., 2017. Replication and translation of co-innovation: the influence of institutional context in large international participatory research projects. Land Use Policy 61, 276–292.
Klerkx, L., Jakku, E., Labarthe, P., 2019. A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. NJAS - Wageningen Journal of Life Sciences 90–91, 100315.
Knierim, A., Boenning, K., Caggiano, M., Cristóvão, A., Dirimanova, V., Koehnen, T., Labarthe, P., Prager, K., 2015. The AKIS concept and its relevance in selected EU member states. Outlook on Agric. 44 (1), 29–36.
Knierim, A., Labarthe, P., Laurent, C., Prager, K., Kania, J., Madureira, L., Ndah, T.H., 2017. Pluralism of agricultural advisory service providers – facts and insights from Europe. J. Rural. Stud. 55, 45–58.
Labarthe, P., Laurent, C., 2013. Privatization of agricultural extension services in the EU: towards a lack of adequate knowledge for small-scale farms? Food Policy 38, 240–252.
Lawrence, G., Richards, C., Lyons, K., 2013. Food security in Australia in an era of neoliberalism, productivism and climate change. J. Rural. Stud. 29, 30–39.
Leonard, E., Rainbow, R., Trindall, J., Baker, I., Barry, S., Darragh, L., Darnell, R., George, A., Heath, R., Jakku, E., Laurie, A., Lamb, D., Llewellyn, R., Perrett, E., Sanderson, J., Skinner, A., Stollery, T., Wiseman, L., Wood, G., Zhang, A., 2017. Accelerating Precision Agriculture to Decision Agriculture: Enabling Digital Agriculture in Australia. Cotton Research and Development Corporation, Australia.
Leviäkangas, P., 2016. Digitalisation of Finland's transport sector. Technol. Soc. 47, 1–15.
Lindblom, J., Lundström, C., Ljung, M., Jonsson, A., 2017. Promoting sustainable intensification in precision agriculture: review of decision support systems development and strategies. Precis. Agric. 18 (3), 309–331.
Lioutas, E.D., Charatsari, C., La Rocca, G., De Rosa, M., 2019. Online. Key questions on the use of big data in farming: an activity theory approach. NJAS – Wagenin. J. Life Sci. 90–91, 100297. https://doi.org/10.1016/j.njas.2019.04.003.
Lubell, M., Niles, M., Hoffman, M., 2014. Extension 3.0: managing agricultural knowledge systems in the network age. Soc. Nat. Resour. 27 (10), 1089–1103.
Lush, D., 2018. The right to farm versus the right to choose: society is having the final say. Farm Policy J. 15 (4), 4–11.
Meadows, J., Emtage, N., Herbohn, J., 2014. Engaging Australian small-scale lifestyle landowners in natural resource management programmes – perceptions, past experiences and policy implications. Land Use Policy 36, 618–627 (0).
Medema, W., Wals, A., Adamowski, J., 2014. Multi-loop social learning for sustainable land and water governance: towards a research agenda on the potential of virtual learning platforms. NJAS – Wagenin. J. Life Sci. 69, 23–38.
Ministry of Defence, 2014. Global Strategic Trends - out to 2045. Ministry of Defence, London.
Murphy, C., Nettle, R., Paine, M., 2013. The evolving extension environment: implications for dairy scientists. Anim. Prod. Sci. 53 (9), 917–923.
Nettle, R., 2017. Workshop Paper: Farmers Adopting and Farmers Benefitting from R&D - where Are we Now? University of Melbourne, Melbourne.
Nettle, R., Brightling, P., Hope, A., 2013. How programme teams progress agricultural innovation in the Australian dairy industry. J. Agric. Educ. Ext. 19 (3), 271–290.
Nettle, R., Crawford, A., Brightling, P., 2018. How private-sector farm advisors change their practices: an Australian case study. J. Rural. Stud. 58, 20–27.
Newell, P., Taylor, O., 2017. Contested landscapes: the global political economy of climate-smart agriculture. J. Peasant Stud. 1–22.
Nyasimi, M., Kimeli, P., Sayula, G., Radeny, M., Kinyangi, J., Mungai, C., 2017. Adoption and dissemination pathways for climate-smart agriculture technologies and practices for climate-resilient livelihoods in Lushoto, Northeast Tanzania. Climate 5 (3).
OECD, 2018. Global Forum on Agriculture: Digital Technologies in Food and Agriculture Reaping the Benefits. OECD, Paris.
Oluboyede, K., 2017. Dookie Dairy. University of Melbourne. https://vimeo.com/232765488/e3d2f193d4.
Oreszczyn, S., Lane, A., Carr, S., 2010. The role of networks of practice and webs of influencers on farmers' engagement with and learning about agricultural innovations. J. Rural. Stud. 26 (4), 404–417.
Pant, L.P., Odame, H.H., 2017. Broadband for a sustainable digital future of rural communities: a reflexive interactive assessment. J. Rural. Stud. 54, 435–450.
Paschen, J.-A., Reichelt, N., King, B., Ayre, M., Nettle, R., 2017. Enrolling advisers in governing privatised agricultural extension in Australia: challenges and opportunities for the research, development and extension system. J. Agric. Educ. Ext. 23 (3), 265–282.
Penzenstadler, B., Tomlinson, B., Baumer, E., Pufal, M., Raturi, A., Richardson, D., Cakici, B., Chitchyan, R., Da Costa, G., Dombrowski, L., 2014. ICT4S 2029: what will be the systems supporting sustainability in 15 years. In: Proceedings of the 2014 conference ICT for Sustainability. Atlantis Press, pp. 30–39.
Phillipson, J., Proctor, A., Emery, S.B., Lowe, P., 2016. Performing inter-professional expertise in rural advisory networks. Land Use Policy 54, 321–330.
Prager, K., Labarthe, P., Caggiano, M., Lorenzo-Arribas, A., 2016. How does commercialisation impact on the provision of farm advisory services? Evidence from Belgium, Italy, Ireland and the UK. Land Use Policy 52, 329–344.
Prager, K., Creaney, R., Lorenzo-Arribas, A., 2017. Criteria for a system level evaluation of farm advisory services. Land Use Policy 61, 86–98.
Preston, H., Allmand, M., 2001. Discovering the information professional: organisational culture in a digital world. Online Inf. Rev. 25 (6), 388–395.
Rattenbury, T., Nafus, D., 2018. Data Science and Ethnography: What's Our Common Ground, and Why Does It Matter? https://www.epicpeople.org/data-science-and-ethnography/.
Regan, Á., 2019. Online. 'Smart farming' in Ireland: a risk perception study with key governance actors. NJAS – Wagenin. J. Life Sci. 90–91, 100292. https://doi.org/10.1016/j.njas.2019.02.003.
Rifkin, J., 2013. The Third Industrial Revolution : How Lateral Power Is Transforming Energy, the Economy, and the World. Palgrave MacMillan, Basingstoke.
Rijswijk, K., Brazendale, R., 2017. Innovation networks to stimulate public and private sector collaboration for advisory services innovation and coordination: the case of pasture performance issues in the New Zealand dairy industry. J. Agric. Educ. Ext. 23 (3), 245–263.
Rijswijk, K., Bewsell, D., O'Callaghan, M., Turner, J.A., 2018. The next generation of biopesticides: institutional barriers and enablers to co-innovation in a science and commercialisation programme. Rural Ext. Innov. Syst. J. 14 (1), 52–61.
Rijswijk, K., Klerkx, L., Turner, J.A., 2019. Digitalisation in the New Zealand Agricultural Knowledge and Innovation System: Initial understandings and emerging organisational responses to digital agriculture. NJAS - Wageningen Journal of Life Sciences 90–91, 100313.
Robertson, M., Keating, B., Walker, D., Bonnett, G., Hall, A., 2016. Five ways to improve the agricultural innovation system in Australia. Farm Policy J. 15 (1), 1–13.
Rose, D.C., Chilvers, J., 2018. Agriculture 4.0: broadening responsible innovation in an era of smart farming. Front. Sustain. Food Syst. 2 Art. 87.

Rose, D.C., Morris, C., Lobley, M., Winter, M., Sutherland, W.J., Dicks, L.V., 2018. Exploring the spatialities of technological and user re-scripting: the case of decision support tools in UK agriculture. Geoforum 89, 11–18.

Rotz, S., Gravely, E., Mosby, I., Duncan, E., Finnis, E., Horgan, M., LeBlanc, J., Martin, R., Neufeld, H.T., Nixon, A., Pant, L., Shalla, V., Fraser, E., 2019. Online. Automated pastures and the digital divide: how agricultural technologies are shaping labour and rural communities. J. Rural. Stud. 68, 112–122. https://doi.org/10.1016/j.jrurstud.2019.01.023.

Schut, M., Klerkx, L., Rodenburg, J., Kayeke, J., Hinnou, L.C., Raboanarielina, C.M., Adegbola, P.Y., van Ast, A., Bastiaans, L., 2015. RAAIS: Rapid Appraisal of Agricultural Innovation Systems (Part I): A diagnostic tool for integrated analysis of complex problems and innovation capacity. Agric. Syst. 132, 1–11.

Shepherd, M., Turner, J.A., Small, B., Wheeler, D., 2018. Priorities for science to overcome hurdles thwarting the full promise of the 'digital agriculture'revolution. J. Sci. Food Agric. https://doi.org/10.1002/jsfa.9346.

Sligo, F.X., Massey, C., 2007. Risk, trust and knowledge networks in farmers' learning. J. Rural. Stud. 23 (2), 170–182.

Stilgoe, J., 2018. Machine learning, social learning and the governance of self-driving cars. Soc. Stud. Sci. 48 (1), 25–56.

Sutherland, L.-A., Mills, J., Ingram, J., Burton, R.J., Dwyer, J., Blackstock, K., 2013. Considering the source: commercialisation and trust in Agri-environmental information and advisory services in England. J. Environ. Manag. 118, 96–105.

Taylor, B., Van Grieken, M., 2015. Local institutions and farmer participation in Agri-environmental schemes. J. Rural. Stud. 37, 10–19.

Thorburn, P.J., Jakku, E., Webster, A.J., Everingham, Y.L., 2011. Agricultural decision support systems facilitating co - learning: a case study on environmental impacts of sugarcane production. Int. J. Agric. Sustain. 9 (2), 322–333.

Turner, J.A., Klerkx, L., White, T., Nelson, T., Everett-Hincks, J., Mackay, A., Botha, N., 2017. Unpacking systemic innovation capacity as strategic ambidexterity: how projects dynamically configure capabilities for agricultural innovation. Land Use Policy 68, 503–523.

Vereijssen, J., Srinivasan, M.S., Dirks, S., Fielke, S.J., Jongmans, C., Agnew, N.M., Klerkx, L., Pinxterhuis, I., Moore, J., Edwards, P., Brazendale, R., Botha, N., Turner, J.A., 2017. Addressing complex challenges using a co-innovation approach: lessons from five case studies in the New Zealand primary sector. Outlook on Agriculture 46 (2), 108–116.

Volwes, E., Story Carter, J., 2018. Your Google Home Or Fitbit Could Be Used Against You In Court. http://www.abc.net.au/news/2018-03-09/your-google-home-or-fit-bit-could-be-used-against-you-in-court/9510368.

Walter, A., Finger, R., Huber, R., Buchmann, N., 2017. Opinion: smart farming is key to developing sustainable agriculture. Proc. Natl. Acad. Sci. 114 (24), 6148–6150.

Wang, J., Hochman, Z., Taylor, B., Darbas, T., van Rees, H., Carberry, P., Ren, D., 2017. Governing through representatives of the community: a case study on farmer organizations in rural Australia. J. Rural. Stud. 53 (Supplement C), 68–77.

Wilson, G.A., 2014. Community resilience: path dependency, lock-in effects and transitional ruptures. J. Environ. Plan. Manag. 57 (1), 1–26.

Wiseman, L., 2016. Changes To Contract Laws Could Give Small Farming Businesses More Control Of Data And Innovation. https://theconversation.com/changes-to-contract-laws-could-give-small-farming-businesses-more-control-of-data-and-innovation-69275.

Wiseman, L., Sanderson, J., Robb, L., 2018. Rethinking ag data ownership. Farm Policy J. 15 (1), 71–77.

Wiseman, L., Sanderson, J., Zhang, A., Jakku, E., 2019. Online. Farmers and their data: an examination of farmers' reluctance to share their data through the lens of the laws impacting smart farming. NJAS – Wagenin. J. Life Sci. 90–91, 100301. https://doi.org/10.1016/j.njas.2019.04.007.

Wolf, S.A., Buttel, F.H., 1996. The political economy of precision farming. Am. J. Agric. Econ. 78 (5), 1269–1274.

Wolf, S.A., Just, D., Zilberman, D., 2001. Between data and decisions: the organization of agricultural economic information systems. Res. Policy 30 (1), 121–141.

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

Xie, C., Sun, Y., Luo, H., 2017. Secured data storage scheme based on block chain for agricultural products tracking. In: 3rd International Conference on Big Data Computing and Communications. IEEE, pp. 45–50.

Zscheischler, J., Rogga, S., 2015. Transdisciplinarity in land use science – a review of concepts, empirical findings and current practices. Futures 65, 28–44.