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The complex adoption pathways of digital technology in Australian livestock supply chains systems

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ABSTRACT

This paper reviews early experiences, expectations and obstacles concerning the adoption of digital technologies in Australian livestock systems. Using three case studies of publicly-available information on Australia's red meat industry, we identify the process of digitally enhanced value creation according to four themes: (1) supply chain operability; (2) product quality; (3) animal welfare; and (4) innovation and learning. We find reasons for both optimism and pessimism concerning the adoption of digital agriculture. While digital technology is being offered by various stakeholders to support collaboration within supply chains, it is also being met with scepticism amongst some producers who are not actively engaging with a digital transformation. We identify that the 'technology fallacy', which proposes that organisations, people, learning and processes are as important to digital transformation as the technology itself; but while digital technologies enable change, it is the people who determine how quickly it can occur. We argue that – since quality appears to be the major basis on which Australian red meat producers will compete in global markets – the broad adoption of digital technology will prove increasingly essential to future growth and sustainability of this supply chain.

Keywords: digital agriculture, farmer learning, farming systems, livestock, precision agriculture, precision farming, supply chain management, value creation.

Introduction

Digital technology is influencing all aspects of economic and social life (Trendov *et al.* 2019*a*). Disruptors such as smart phones, ride sharing companies and online marketplaces for lodgings are examples of changes that are happening in all sectors of the global economy (Fowler 2015; Geissinger *et al.* 2020). Digital transformation, as a goal and as a process, has been variously defined as the incorporation and uptake of digital technologies (Rijswijk *et al.* 2019, 2021; Cook *et al.* 2021). It also includes the reorganisation of firms and their business models to take best advantage of digital technologies while networking within value chains and the broader society (Bowersox *et al.* 2005).

Despite agriculture being described as the least digitised of all sectors in the US and Australian economies (Blackburn *et al.* 2017; Trendov *et al.* 2019*b*), rapid change is being sought through changes such as equitable access to helpful data sources and trust mechanisms to safeguard the misuse of data (World Bank 2021*a*). Globally, there are expectations that digital technology will bring transformational changes in sustainable agriculture (Government Office of Science 2011) and economic growth (Chavas and Nauges 2020), although the changes are mostly yet to happen. While agri-food supply chains are enjoying considerable new investment (Burwood-Taylor 2020, 2021), attracting about USD30 billion (in 2020), this is a fraction of the global value of food systems estimated at about USD8 trillion (van Nieuwkoop 2019).

Digital agriculture has been defined as 'the use of detailed digital information to guide decisions along the agricultural value chain' (Shepherd *et al.* 2020:5084). It is anticipated to deliver major benefits to Australian agribusiness through gains in productivity and value. Annual gains of more than AUD20 billion are anticipated (Perrett *et al.* 2017; Heath 2018). The major advances are expected in the grains and livestock industries, largely because of their scale (Perrett *et al.* 2017; Heath 2018). However, rapid growth is also sought in high-value export products for which Australia has a competitive advantage (Agrifutures Australia 2018). Despite the need for rapid growth to reap the espoused benefits of digital agriculture, critical comment exists. For example, Eastwood *et al.* (2021) argue that the benefits of digital agriculture are uncertain and are obscured by what they term in their analysis to be the 'weight of the past'. Ingram *et al.* (2022:2) cite a plethora of works critiquing 'agri-food tech solutionism' with themes mentioned around over-confidence in digital systems, under-estimation of expectations and disconnection between policy-makers and technology users. While the promises of digital agriculture are great, it is important to take a balanced view of the technology and its adoption.

Adoption of digital technology in agribusiness is largely driven by value creation, which can occur throughout the food system within domains organised broadly according to production, market, capital and governance (Cook *et al.* 2021). In this respect digital agriculture could be considered to differ from precision agriculture, which has been concerned mainly with improved efficiency of on-farm production. A further contrast with precision agriculture is that lessons from digitisation in other sectors has demonstrated that achieving significant industry-wide change also requires attention to organisational issues. Failure to address these leads to the so-called 'technology fallacy' whereby human response to technology are the drivers of change, rather than the technology itself (which is the enabler of change) (Kane *et al.* 2019).

Here, we focus on the potential for digital agriculture within livestock supply chain systems in Australia. Recent publications (such as Herlin *et al.* 2021 and Groher *et al.* 2020) identify some of the potential for digital agriculture in livestock systems from a technical perspective. Taking into account that adoption depends strongly on value creation within supply chains and the organisational issues that determine who realises value outcomes, we take a supply chain focus to understand: (1) the potential for digital agriculture in livestock supply chains in Australia; (2) the implications for innovation within them; and (3) through case studies, some of the organisational realities that determine how change is likely to occur.

Digital agriculture in Australian livestock systems

This section lays out the digital change process in Australian livestock systems by identifying change in relation to four themes:

1. How digitally-enabled traceability creates value within livestock supply chains;
2. Value creation through product quality and digital agriculture;
3. The value created by farmers through good animal welfare practises; and
4. The effect of digital technology on innovation trajectories affecting livestock systems.

These themes were selected from an initial review of the literature and discussion with contacts in the industry in line with Seuring (2008), who stresses the importance of real world approaches to supply chain management research and strongly advocates that case studies are an effective method of directly observing industry applications of supply chain theory. With Seuring's (2008) work in mind, this research uses case studies selected for their organisational phenomenon and place in the digital transformation of agriculture in Australian livestock supply chains. Three case studies were selected to illustrate the disparate nature of Australian livestock supply chains and how change is being handled by different types of organisations. Selection of the case studies was focused on understanding how change is enabled by digital systems, value creation, technology adoption and learning, organisation/structure/ownership and digital benefits to animal welfare. Analysis was undertaken solely through public sources of information (e.g. websites, annual reports, project reports) to demonstrate activity in digital transformation of Australian livestock supply chains. Since secondary sources of data were used for this research, no ethics approval was required.

How digitally-enabled traceability creates value within livestock supply chains

Traceability and transparency facilitates trust amongst food buyers, manufacturers and consumers by way of understanding and guaranteeing credibility of provenance (Galvez *et al.* 2018; Pearson *et al.* 2019) with several issues at the forefront of concern: food safety (Zhang *et al.* 2020), food security (HLPE 2020) and environmental impact (Macready *et al.* 2020; World Bank 2021*b*). In more recent times, the benefits of such systems have been realised from a supply chain efficiency point of view; among others such as monitoring waste and environmental impact (World Economic Forum 2019). The dependency upon agri-food traceability systems is evidenced by their inclusion in legislation at the international level such as the European Union's General Good Law (European Commission 2002) and in national–level legislation like the United States' FDA Food Safety Modernization Act (FDA 2017).

Traceability and transparency are managed and measured through increasingly complex information technology platforms that collect data on food quality and quantity parameters (International Trade Centre 2015). Industry 4.0 is a broad term that describes the fourth industrial revolution that applies electronic and information technologies to manufacturing processes (Zambon *et al.* 2019); these principles are introducing new traceability technologies to food systems at an increasing rate (Trendov *et al.* 2019*b*). Traceability technologies in food systems closely overlap with the concept of Agriculture 4.0 (Klerkx and Rose 2020), which incorporates technologies such as the internet of things (IoT), artificial intelligence, precision agriculture, advanced robotics, nanotechnologies, gene editing and the 'omics'[1] into agri-food systems (Rose and Chilvers 2018; Rose *et al.* 2021). The ultimate aim of these advancements is to increase agricultural productivity while also minimising negative impacts on environmental and social outcomes (Trendov *et al.* 2019*b*).

Initial uses of these Agriculture 4.0 technologies and their data outputs were to mitigate the risk of disease outbreaks and send food quality and quantity information downstream to prove provenance to customers and consumers in industries such as fruit, vegetables and meat (Choe *et al.* 2009). More recently, digital platforms such as blockchain are being used to send data in the opposite direction (upstream) as a feedback mechanism from the retailer back through the chain to the producer, as well as offering compliance with international food safety laws (Qian *et al.* 2020).

The outcome of this bi-directional flow of data is two-fold: firstly, to support supply chain collaboration through information sharing (FAO 2009; World Economic Forum 2019); and secondly, to enable evidence-based decision making through access to supply chain data (International Trade Centre 2015; FAO 2016). From a production point of view, data and its analytics are enabling more exacting decisions to be made on-farm so outputs are targeted more to customer and consumer needs than ever before (Trevarthen 2007). Examples in the livestock sector include genetics databases related to estimated breeding values for wool and meat production. These systems allow producers to breed and produce livestock that meet the exacting requirements of different market segments, whether that be for heavily-marbled meat for the Japanese market, lean meat for the Australian market or even new products that are yet to emerge (Greenville *et al.* 2020).

Australian agricultural systems are net exporters of food; far more food is produced than can be domestically consumed and despite challenges brought about by issues such as climate change, geopolitical interventions in agricultural trade and market-led changes, Australia's agricultural output continues to increase in terms of value and volume (Keogh 2020; Kingwell 2020). Due to Australia's relatively small contribution to global agricultural trade and high costs of production, value creation is essential for remaining competitive in the global market (White *et al.* 2018). While value can be created through product attributes, such as taste and eating quality (Polkinghorne *et al.* 2008), value created using data and technology to minimise costs, reduce error and share knowledge through increasing complex supply chain systems is well-worth considering (Trevarthen 2007; Lima *et al.* 2018). Methods of using digital agriculture in Australian livestock system for value creation are discussed in the following sections of this paper by considering two aspects of value creation: creating value through product quality and then addressing animal welfare as an inimitable aspect of value in livestock systems.

Value creation through product quality and digital agriculture

Evans and Lindsay (2019) discuss the creation of value through product quality at length and report on the positive outcomes of organisations that focus on product quality: higher perceived value, increased prices, increased market share, increased revenues and higher profits. But Christopher and Gaudenzi's (2009) seminal finding that it is no longer individual businesses that are competing for consumer attention suggests that it is in fact the collection of individual businesses that collaborate to generate genuine competitive advantage through integrated product value creation. Freudenreich *et al.* (2020) and Hoskisson *et al.* (2018) assert that value creation must be an inclusive process and caution against ignoring the needs of customers, suppliers, and employees. In essence, supply chain collaboration is arguably the key to creating value (Horvath 2001); a principle that has long been known and is widely accepted (Ralston *et al.* 2017; Shibin *et al.* 2020).

Against this background, the next question to address is how does this supply chain collaboration happen for product value creation to be achieved in the Australian red meat industry? The answer lies in supply chain connectivity, or the sharing of information through the supply chain for making better business decisions on product quality (Alsaad *et al.* 2018); the food industry follows identical principles (Allaoui *et al.* 2019; Zhang *et al.* 2020). While collaboration is an important step in product value creation, it is only possible through information systems. Information systems are becoming increasingly sophisticated through improvements in machine learning, digital twins, blockchain, cloud computing and big data analytics (Stefanovic and Milosevic 2019; Aryal *et al.* 2020; Queiroz *et al.* 2020). The bottom line is that supply chains (and the businesses within) can achieve competitive advantage by making use of rare and inimitable resources such as high-quality shared data (Zhang *et al.* 2020). In the case of Australia's red meat

[1]The Committee on the Review of Omics-Based Tests for Predicting Patient Outcomes in Clinical Trials; Board on Health Care Services; Board on Health Sciences Policy; Institute of Medicine (2012) defines 'omics' as 'the scientific fields associated with measuring such biological molecules in a high-throughput way … Examples include proteomics, transcriptomics, genomics, metabolomics, lipidomics, and epigenomics, which correspond to global analyses of proteins, RNA, genes, metabolites, lipids, and methylated DNA or modified histone proteins in chromosomes, respectively.'

supply chain, value will be created not only through perceived eating quality, but also through the industry's capability to collaborate and share data to further enhance product quality, processing and production efficiencies.

Value creation in livestock through animal welfare

Unlike the profit-maximising nature of many supply chains, value creation at different parts of the livestock supply chain occurs for reasons other than financial gain (Sansoucy 1995) and it has long been known that the human–animal bond goes beyond farmers' economic dependence on livestock (Croney 2014). Wilson's (1993) biophilia hypothesis suggests that, despite increasingly mechanical human–animal interactions in farming systems, humans have a primordial instinct to attend to animals. Advances in animal science and production systems are keenly focused on animal welfare with much attention being paid to precision farming and digital support tools (Bahlo *et al.* 2019).

Norton *et al.* (2019) discuss the positive impact of digital agriculture on 'reuniting' farmers with their livestock. These authors argue that economic and societal pressures have increased herd and flock sizes over time, the management of which has left farmers little time to interact with their livestock to informally monitor welfare and sustainability, and therefore make good management decisions. The welfare implications of using digital agriculture to improve the humanity and sustainability of livestock systems is significant but is very focused on production, rather than beyond the farm gate (Groher *et al.* 2020; Herlin *et al.* 2021). For example, camera surveillance has been used to monitor aggressive behaviours in pigs (Faucitano 2001; Bracke *et al.* 2002) and chickens (Bright 2008). It has also been used to monitor pigs' drinking behaviours (Madsen and Kristensen 2005; Andersen *et al.* 2014). Audio sensors have also been used to monitor distress calls in livestock (Zimmerman *et al.* 2000; Bokkers and Koene 2001; Cordeiro *et al.* 2018). Sensor technology is being used to monitor the welfare of pre-natal and post-natal cows and calves in highly remote locations in Australia (Future Beef 2021). Sensor technology is also reducing labour and fuel costs associated with monitoring water points in these highly remote locations in Australia ensuring livestock have adequate access to water while pastoralists can spend the significant time usually devoted to 'water runs' on other management activities (Welburn 2020). Trotter *et al.* (2018) took an alternative perspective and researched the economic value of animal location and behaviour data in the red meat value chain and found that not only did the digital technology used in their work improve animal welfare, but there was also financial gain of 6.8% in increased revenue and 3.8% in cost savings. Also noteworthy is the success achieved by New Zealand's cattle industry in its ambition to eradicate *Mycoplasma bovis* from the national herd. Shadbolt *et al.* (2021) discuss the impact of using digital traceability systems to share data about disease transmission. They report that the nation is on-track to eradicate the disease and provide valuable lessons about farmer engagement with the technology on the basis of disease monitoring and data sharing.

Despite the maturity and positive outcomes of these technologies on production and animal welfare, more work is needed on the governance and structures of the public and private repositories that hold the large amounts of data being collected from these systems across Australia (Bahlo *et al.* 2019; Lockie *et al.* 2020); the global nature of organisational disclosure systems also needs consideration (McLaren and Appleyard 2022). The Business Benchmark on Farm Animal Welfare initiative (see: https://www.bbfaw.com/) provides evidence that animal welfare is emerging as a potential element in sustainability metrics. This points to the long-term view of transformative digital technologies that will facilitate the much-needed collaborative thinking needed throughout stakeholder networks on animal welfare (Fernandes *et al.* 2019) and capture data for supply chain value creation (Fernández-Mateo and Franco-Barrera 2020).

Innovation within supply chains

Traceability, digital agriculture and value creation complement the widespread research on technological innovation systems and all constitute catalysts for change in livestock production systems but adoption of innovations is also a social and organisational process (Kane *et al.* 2019). Despite all the espoused benefits of technical systems that facilitate value creation, broad-scale adoption has been relatively slow (Blackburn *et al.* 2017). Greenville *et al.* (2020) argue that value creation is more than an upstream activity, suggesting that it is the responsibility of the whole economy and it can come in different guises from product differentiation (e.g. creating flour from grain) or adding a new attribute to an existing product (e.g. evidence of provenance through traceability of meat or wool).

Denis *et al.* (2020) attribute the complexity of agricultural value chains as a reason for slow adoption of digital and analytics technologies while Shepherd *et al.* (2020) view the issue of slow adoption from an institutional perspective and suggest that change is needed at the socio-ethical level, as well as the technical level. By this, they mean that a systems approach is required for the adoption of digital agriculture through changing supply chain operations, development of business models in the processing and retail sectors, agile thinking, good project management and the development of new capabilities: this is change at the organisational and institutional levels as well as at the farm level.

Despite the wide ranging reasons for slow adoption of technical agricultural innovations, we consider the work of

Shepherd *et al*. (2020) and Klerkx *et al*. (2019) who argue that change and adoption need to occur at the socio-ethical level of agriculture where learning matters and support is needed to equip technology users with skills and confidence for wide-spread, transformational adoption of value-creating innovations that includes elements like trust in provenance claims at that are important to members of the wider supply chain (Lockie *et al*. 2020). Kane *et al*. (2018) and others stress the importance of experimentation as a process by which organisations innovate. This is the so called fast-fail philosophy of agile development. The process is as follows:

1. Supply chain actors explore deliberate variation.
2. Data and analysis identifies how variants influence performance in relation to goals of efficiency or value within the value chain.
3. Supply chain actors evaluate the options and adjust, move on.
4. The supply chain reconfigures around the actors.

We focus on farmers first but similar processes could occur anywhere within supply chains for which there are exploitable variation, data/analysis to indicate the outcome of the trial, including data that indicate the stability under external influences and rewards/incentives for supply chain actors to change.

The operation of the supply chain matters enormously, particularly its degree of integration. At one extreme, a supply chain might lack aggregation. Individual actors are insensitive to changes elsewhere in the supply chain, for example, amongst consumers, and fail to develop. They may become highly efficient, tuned to perfection for a particular configuration within a segment of a supply chain. But for many, this is not considered a sustainable condition.

The alternative is a supply chain in which the activities of individual actors are collaborative and well-coordinated with one another. Signals from one end of the value chain are perceived clearly at the other end; adjustment is rapid (agile) and new opportunities create value throughout the chain.

Despite the positive outlook of Australia's commodity export system espoused by Greenville *et al*. (2020), some producers have recognised the opportunities that Keogh (2020) discusses by looking beyond the commodity marketing system to explore premium markets. They are experimenting with business and supply chain systems: increased consumer demand for premium produce, maintaining consumer trust in product claims and creating transparent pricing systems to diminish the problems associated with information asymmetry of pricing. This change has been particularly prominent in Australia's livestock sector where consumer demand for transparency and ethical production systems are critical components of high-value, value-added product.

Case studies

In this section, we use case studies to demonstrate how digital transformation is changing Australia's livestock sector to ensure premium prices for premium products are being sustainably achieved. The first case study outlines the situation of electronic identification systems that facilitate digital communication in Australia's sheep industry. The second case study uses the Australia-wide Integrity Systems Company to demonstrate supply chain transformation and organisational change for nation-wide value creation in the red meat sector; this is a top-down approach where change is occurring at the industry-level. The third case study uses the WA Producers' Co-operative as an example of how experimentation with digital agriculture is enabling a small group of livestock producers in the south-west of Australia to circumvent the mature sheep meat commodity system to seek premium markets; this is a bottom-up approach where change is occurring at the farm-level.

Case study 1: eID and the Australian sheep industry

Electronic identification (eID) of livestock is an RFID-based technology that enables various attributes throughout an animal's life to be tracked. Such attributes include, but are not limited to, place and date of birth, husbandry practises, movement through the supply chain and processing (Choe *et al*. 2009). Like many digital technologies in agriculture, the national adoption of eID technology in the sheep industry has been slow compared to adoption rates in other countries for other species where adoption of traceability technology has been mandated by policy (Choe *et al*. 2009). Low adoption rates of supply chain traceability technology risk the trust in which customers of Australian sheep meat and wool have in the provenance and quality of the product they are buying (Bosona and Gebresenbet 2013; Aung and Chang 2014). Given the export-orientated nature of Australian sheep meat and wool, threats to loss of export markets are catastrophic. What follows is an example of digital agriculture in Australia's livestock sector that promises value creation (in its different guises) but which has to date, seen low levels of adoption.

Animal Health Australia (2021*a*) describes The National Livestock Identification System (NLIS) and how it began for cattle in the late 1990s following a spate of national and international events that compromised biosecurity and animal welfare (the system incorporated sheep and goat production systems in 2006); the 2001 outbreak of foot-and-mouth disease in the UK was one such event that sent shock waves through livestock systems throughout the world. The NLIS aims to enable the lifetime traceability of animals by: (1) identifying each animal (by an ear tag; (2) each physical locations (by a Property Identification Code, PIC); and (3) a national database to hold this

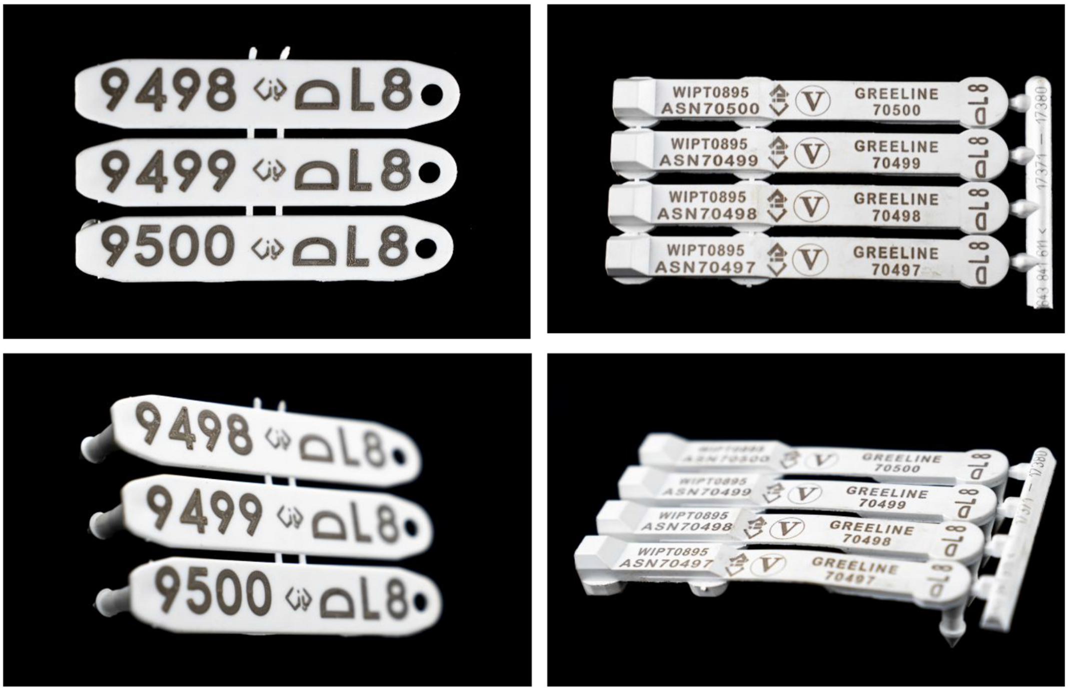

Fig. 1. Sheep ear tags used in Western Australia. Tags on the left are 'visual tags' and show the producer's brand ('lazy D'L8) and sheep numbers 9498–9500. Tags on the right are eID tags; they contain an RFID tag and show the producer's brand ('lazy D'L8), sheep numbers 70 497–70 500 from the producer's 'Greeline' flock and Property Identification Code WIPT0895.

information. It is ISO9001 certified, audited by Animal Health Australia and provides data for disease monitoring, chemical contamination, market access and is considered an inimitable method of demonstrating the safety of Australian red meat (Animal Health Australia 2021*a*). The importance of this system developed by Animal Health Australia is evidence of wider industry's recognition of the need for digital systems to create value and manage risk as it constitutes major action by industry to lead national-level change.

Prior to the advent of eID technology, the NLIS operated on a paper-based system that used plastic livestock ear tags (known as 'visual tags') that contained the animal number and the property number (see Fig. 1). Under the auspices of the NLIS, the antiquated tag system was replaced by an RFID-based technology (as discussed by Trevarthen 2007). Stakeholders in Victoria noticed that the existing system did not meet Standard 1.1 of the National Livestock Traceability Performance Standards (Agriculture Victoria 2021): 'Within 24 h of the relevant [Chief Veterinary Officer] being notified, it must be possible to determine the location(s) where a specified animal was resident during the previous 30 days.' (Animal Health Australia 2021*b*). The Victorian government responded in 2016 by committing AUD17 million to a transition fund that would oversee the mandatory adoption of eID technology for all sheep and goats leaving farms in Victoria by 2022 (Agriculture Victoria 2021). Four years after the announcement, a rigorous, independent review was conducted to evaluate Victoria's sheep eID system with the aim of comparing the efficacy of the old ('visual tag') system with the new (eID tag) system (SAFEMEAT Jurisdictional Traceability Group 2020). To reduce bias, the evaluation was carried out by New South Wales Department of Primary Industries and Biosecurity Queensland, with support from Agriculture Victoria. Results were peer reviewed by the Department of Primary Industries and Regional Development in Western Australia. The evaluation took a supply chain perspective and assessed 2723 sheep from seven different saleyard lines in a 30-day period (aligning with the requirement of Standard 1.1 of the National Livestock Traceability Performance Standards) and included data from all points of sale through the lifetime of each sheep in the study. Unsurprisingly, results showed that traceability from eID tags to be substantially more accurate and efficient than from visual tags[2]. Regardless of these results and the nation's commitment to the NLIS and its standards, at the time of writing this paper, discussions continue about the suitability of this technology. Resistance to its nation-wide adoption persists from some farmer advocacy groups (Sim 2021) and demonstrates the heterogeneous nature of technology adoption between farms and regions

[2]At the time of writing, detailed outcomes of the research remain confidential and are therefore unable to be discussed in further detail.

Table 1. An example of the adoption of electronic identification (eID) ear tags in sheep. Data from Western Australia [Source: adapted from Curnow and Conte (2019)].

	2011	2014	2018
Proportion of respondents using eID tags (%)	4	4	5
Proportion of respondents considering using eID tags (%)	20	16	31
Sample size	369	368	389
Total sheep numbers	4720	4402	4210

(Chavas and Nauges 2020). Adoption data of eID technology adoption are sparse but Table 1 provides some insight into the situation in Western Australia where technology adoption data are available over three time periods. The data suggests that adoption is very low despite systems that have been put in place by Animal Health Australia's NLIS. While numbers of farmers considering adopting the eID technology have increased in 2018, actual adoption does not meet this optimism and only changed from 4% to 5% of those sampled between 2014 and 2018.

This practical example of the slow adoption of a digital agriculture innovation demonstrates a concerning problem. The NLIS is focused on animal welfare, biosecurity and value creation (through developing trust and brand reputation). Yet, strong evidence of its efficiency and accuracy proved insufficient to result in wide-spread adoption of the technology. This case provides an example of an adoption problem centred in user perceived value of the eID system; a system that aims to create value for Australia's sheep industry. Despite policy interventions, availability of digital systems to create value and evidence of its operability for managing biosecurity threats, promoting good animal welfare practises and securing markets, genuine digital transformation is failing due to human behaviours and attitudes.

Case study 2: The Integrity Systems Company and nation-wide learning

Value creation can be realised through several strategies in agribusiness (Greenville *et al.* 2020). Meat and Livestock Australia (MLA) is Australia's red meat, grower levy-funded research and development corporation. It develops and markets new red meat products for the international market but it also recognises the importance of value creation through the addition of improved product attributes. In this case, the improved product attribute is product integrity through traceability and we demonstrate herein how digital transformation is taking place to support the value creation process.

In the absence of sophisticated supply chain data systems, product integrity is an intangible product attribute and therefore difficult to measure. Product integrity is a typical credence attribute which Darby and Karni (1973) explained are considered worthwhile in a product offering but are of uncertain value under normal use conditions. Sometimes even after purchase. MLA recognised this challenge and launched its Integrity Systems Company ([ISC]; https://www.integritysystems.com.au/) in 2016 based on recommendations from Australia's federal government through the SAFEMEAT partnership. Through its mission to 'to grow red meat value chain opportunities through integrity and information systems innovation. It is essential to enhance our systems and technologies to stay ahead of our global competitors, maintain our point of difference, and enable Australia's red meat industry to capture price premiums from consumers and customers who are willing to pay more for higher levels of product assurance.', the ISC manages and delivers three key on-farm digital assurance programmes: (1) Livestock Production Assurance (LPA) programme; (2) LPA National Vendor Declarations (LPA NVD); and (3) National Livestock Identification System (NLIS) (all of which are certified under the ISO 9001:2015 standard) (Integrity Systems 2021). As such, the ISC is an example of a digital agriculture system focused on value creation through measurable supply chain performance so warrants attention in value creation in Australia's red meat supply chain.

The ISC has been particularly prescient in recognising the need for ongoing producer education and engagement as it matures as an organisation. This is evidenced through its producer engagement strategy, which aims to connect with supply chain actors to promote adoption and appreciation of the integrity systems and its effective use. As such, this case study provides an example of digital systems design and stakeholder learning in transforming what is arguably a very mature supply chain. Latest data suggests that 101 792 people have completed LPA learning modules and there have been 154 626 helpdesk enquiries (in FY2019); one ISC survey respondent said '[LPA learning] gave me a holistic view of the Australian livestock industry and of the importance for sound management practises. It made me quite proud of the industry standards that this nation has set.' (Integrity Systems 2019).

Adoption of the systems and digital innovations that lay at the heart of the ISC is recognised throughout its strategic plan. In fact, the term 'adoption' is mentioned 21 times in the document and the term 'adopt' is mentioned 28 times. Barriers to adoption are also given consideration with nine constraints noted, each with an associated mitigation strategy. At the top of this list is 'Unwillingness to change within industry'. However, the encouraging part of this case study is that we are witnessing the type of organic four-step progress described previously this paper, which we present in Table 2 as an analysis of the change process. Most encouraging is that change is occurring at the supply chain level, not just at the organisational level which Denis *et al.* (2020) identified as a significant barrier to the adoption of digital agriculture innovations. We are also witnessing

Table 2. The four-step process of organisational process improvement in the contact of the ISC case study.

Theoretical process	Time	Observations from the ISC case study
(1) Supply chain actors explore deliberate variation	Prior to 2006	Traceability, transparency and integrity operated *via* a paper-based system in the absence of any digital technology. Variation is significant in the existing system
(2) Data and analysis identifies how variants influence performance in relation to goals of efficiency or value within the supply chain	2006 - 2015	Partnerships in Australia's red meat industry are formed to advance the paper-based integrity system with the aim of value creation through the improved product attribute of integrity
(3) Supply chain actors evaluate the options and adjust, move on	2016	Launch of the ISC with adjustments being made to value creation through the phase-out of paper-based systems to purely digital integrity systems
(4)The supply chain reconfigures around the actors	Strategic plan for 2025	Significant investment is being put into using digital technology for a robust, reliable integrity system; minimal variation in integrity system data and use of the system

progress observed by Kane *et al.* (2018) in terms of digital leadership and the ISC. These authors suggest that digital maturity comes with feeding the needs of digital leaders, which is what we see in the ISC through its experimentation, education processes and feedback system from technology users (Integrity Systems 2019). This is all with the aim of value creation.

Case study 3: WA Producers' Co-operative and farmer group learning

The case study on the ISC provided an example of a national-scale initiative that incorporated learning into a strategy for dealing with change by means of the development and adoption of digitised agriculture from a technology and socio-ethical point of view (as recommended by Shepherd *et al.* 2020). This final cases study on the WA Producers' Co-operative (WAPC) presents an example of transformation within a far smaller, but not less significant, endeavour for creating value from digitised agriculture. The WAPC deals with lamb, beef and niche grain (WAPC 2021*a*) but this case study will focus on the livestock aspect of the business.

Established in 2019, the WAPC is a member-based, micro-business in Albany, Western Australia, that uses co-operative principles to supply premium agricultural products direct to international customers, thereby circumventing downsides of the commodity system like price-taking and information asymmetry (Roche 2020), all enabled by digital innovations. As discussed in the section of this paper on value creation through traceability, traceability and transparency are innovations being used to facilitate trust amongst food buyers, manufacturers and consumers by way of understanding and guaranteeing credibility of provenance. Fig. 2*a, b* illustrates Australia's generic, commodity-based red meat supply chain and that of WAPC, respectively. The WAPC's supply chain has been designed to streamline the number of actors to reduce transaction costs, improve collaboration and create a valued, bi-directional flow of information for evidenced-based decision making. The transformation to digital systems is enabling this innovative supply chain design and feedback loop.

Seven reasons are listed for development of the WAPC: (1) collective bargaining and negotiation on behalf of farmers for higher prices; (2) more cost-efficient supply logistics co-ordination; (3) aggregated supply of product to specification to achieve market power; (4) assistance for members to improve productivity and uptake new technology on farm through support programmes and training; (5) provide opportunities for members to add value to basic commodity products; (6) opportunities to seek out new, high value markets for members; and (7) enable members to prove safety and provenance of products to help differentiate, segregate and brand for niche premium markets (WAPC 2021*a*). This list provides insight into the priority WAPC is giving to value creation, digitised agriculture and learning.

Value creation is at the forefront of the WAPC's rationale, as evidenced by its vision ('To be a farmer-owned co-operative for Western Australia delivering and protecting sustainable value for current and future members') and mission ('To become a co-operative capable of offering valued services to its members, including: commodity supply aggregation and logistics co-ordination; branding, [quality assurance] and product traceability; supplementary feeding and nutrition programmes; market development; and provision of other support that adds value to members' farming businesses'). The business is in its start-up phase and progress has been severely limited by Covid-19 disruptions and trade uncertainties between Australia and China yet value creation through collaboration (facilitated by digital technology) between producers, processors and customers remains its key activity.

Its mission statement provides further evidence of the WAPCs ambition for digital technology to broaden product attributes beyond quality to include quality assurance and traceability; as suggested by Greenville *et al.* (2020). Here, we see an example of value creation through digitised systems. We also observe value creation through guaranteed

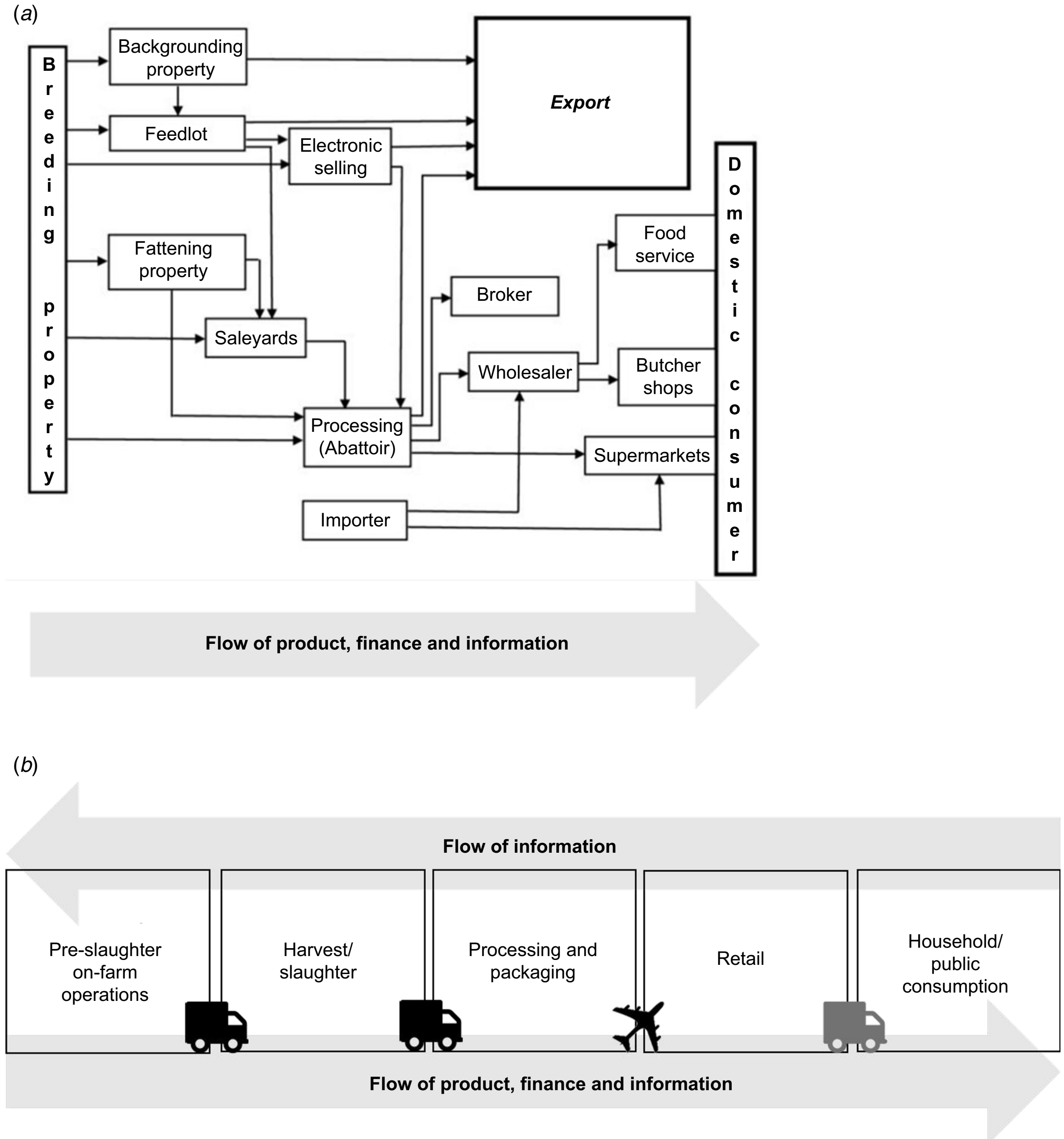

Fig. 2. (*a*) A typical Australian red meat supply chain showing a uni-directional flow of products, finance and information with numerous actors [adapted from Greenwood *et al.* (2018:995)]. The supply chain shares many characteristics with a typical commodity supply chain with numerous actors and opportunities for information asymmetry. Note that this figure does not include transportation services where product integrity can be compromised. (*b*) The WAPC supply chain showing reduced supply chain actors and bi-directional flow of product information for improved evidence-based decision making [adapted from FAO (2019:11)].

high welfare practises. The WAPC's Level 1 QA code (completed by all producers) ensures livestock, which are sold under the WAPC brand adhere to both best-practise animal welfare standards throughout their lifetime and all participating businesses practise top-standard biosecurity. Furthermore, members must be registered with the Meat Standards Australia scheme, which is the national beef, lamb and sheep meat eating quality programme (WAPC 2020).

Accreditation schemes and quality assurance programmes are strategies to give value to credence attributes, or attributes with intangible features or features such as animal welfare, biosecurity and meat eating quality that are difficult to determine pre-purchase or at all (Hobbs *et al.* 2005;

Cicia and Colantuoni 2010). WAPC has covered a number of bases in this respect. But in adopting the technology to prove the quality and premium value of its products, it has also included important educational and support programmes to ensure the digital technology is used correctly. As recognised by the ISC in the previous case study, poor technology adoption and incorrect use are threats to WAPC's success of value creation through traceable products.

WAPC has seven guiding principles, one of which is dedicated to education, training and information. The mission statement also states that WAPC will '[provide] other support that adds value to members' farming businesses.' (WAPC 2021*b*). In collaboration with the Stirlings to Coast grower group (https://www.scfarmers.org.au/), the WAPC has two producer demonstration sites (known as 'Smart Farms'), which are centres of learning and experimentation for the co-operative's staff and its members. Current projects are focused on better understanding a range of digital agriculture tools, including digital weather stations, GPS trackers, soil moisture probes, tank sensors and cross-farm connectivity technology (e.g. wireless internet, WiFi and LoRaWAN) (Stirlings to Coast 2021). The WAPC also has access to the Stirlings to Coast Smart Farm Co-ordinator who is employed on a full-time basis to conduct research and provide support for members in the adoption and development of their digital agriculture.

Discussion

The purpose of this paper was to provide examples of the following for the Australian livestock industry:

1. How digitally-enabled traceability creates value within livestock supply chains;
2. Value creation through product quality and digital agriculture;
3. The value created by farmers through good animal welfare practises enabled by digital technology; and
4. The role of digital technology in supporting innovation within livestock systems.

From the three case studies, we observe grounds for both optimism and pessimism concerning the anticipated transformation of livestock industries through the adoption of digital technologies. Against the background of key themes discussed earlier in the paper, we summarise these changes as observed in Table 3 and explain them below. The case study method (described in the section on digital agriculture in Australian livestock systems) was chosen as a way of demonstrating how supply chain theory is being played out in the context of the paper.

How digitally-enabled traceability creates value within livestock supply chains

The three case studies provided examples of disparate approaches and attitudes towards digitally-enabled traceability creating value within Australian livestock supply chains. Adoption of eID technology in the sheep industry is fragmented and there is little value from the technology perceived by many producers despite the literature that spruiks of promising gains from digital technologies (Perrett *et al.* 2017; Heath 2018). The other two case studies provide examples of how digital transformation is a key source of accreditation for substantiating high-quality product attributes like provenance and good animal welfare practices.

Our findings concur with Shepherd *et al.* (2020) and Klerkx *et al.* (2019) who suggest that change and adoption from agricultural innovations occurs at the socio-ethical level

Table 3. The anticipated transformation of livestock industries through the adoption of digital technologies in four areas: (1) supply chain operability; (2) product value; (3) animal welfare; and (4) innovation and learning.

	Change enabled by digital technology	Case study 1: eID and sheep	Case study 2: ISC of the MLA	Case study 3: WAPC
Supply chain operability	Demand	Traceability of animal movement needed to address international buyers' concerns	Supply chain data system provides product integrity	Market access for premium product through confirmed provenance
	Organisation	Part government mandated	Industry-led (funded by farmer levies)	Farmer-owned co-operative
Product value	Where value is created	Fragmented. Many farmers perceive no additional value	Multiple entry points anticipated through certified product integrity	Accreditation and QA of premium meat and grain products
Animal welfare	Biosecurity monitoring and reporting	Little perceivable change	Anticipated, in line with consumer expectations	Animal welfare stated as a key product attribute
Innovation and learning	Learning	Varied and fragmented farmer attitudes (in the absence of policy intervention)	Anticipated through experimentation, education and feedback with users	Education, training and support are guiding principles
	Adoption	Low, despite varied government mandate	Industry adoption occurring through an organic process	Farmer-owned co-operative (high adoption)

where human interactions, learning and support create innovations and change (Lockie *et al.* 2020). The case of WAPC provides an example of this. We suggest that value creation is not just about creation of wealth but also the creation of intellectual and social capital. The examples of the ISC (case study 2) and WAPC (case study 3) provided evidence of this with the efforts being made to increase learning and promote education through digital transformation in Australia's livestock industry.

Kane *et al.*'s (2018) technology fallacy is illustrated by the case of nation-wide adoption of eID in the sheep industry whereby the technology is operational but adoption is compromised by people not accepting the shared benefits of digital transformation. The ISC's education programmes and support services align with the literature on how to affect change. In fact, the role of farmers as innovators reveals the complexities of technology adoption within segmented supply chains. In the case of sheep eID, technology is seen as necessary to address concerns of international markets arising from historical problems. Little innovation is seen and farmers adopt the technology slowly. By contrast, digital technology in the ISC and WAPC case studies involves farmers in an ongoing process of experimentation, learning and feedback within the supply chains.

Value is understood by supply chain participants to be created largely through product accreditation, especially for premium products marketed by the WAPC. Integration of the supply chain supports value creation at multiple points within the chain. While there is plenty of literature to recommend the benefits of collaboration in agri-food supply chains (León-Bravo *et al.* 2017; Zaridis *et al.* 2021), the more fragmented nature of the sheep supply chain reduces the opportunity for value creation and provides evidence of the real world difficulties of organising collaborative relationships. In this case study, adoption was proving most difficult due to the heterogeneous attitudes towards the technology across farms and regions; a phenomenon described by Chavas and Nauges (2020).

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Creating value through product quality enabled by digital agriculture

The section on value creation through product quality and digital agriculture concluded by citing Zhang *et al.* (2020) and their findings concerning the use of data and data systems to achieve competitive advantage. Australia's red meat supply chain provides examples. The ISC and WAPC case studies shed light on how this occurs and provide examples of how large and small organisations within Australia's red meat sector are adopting data systems for competitive advantage. Determination of quality remains elusive (Darby and Karni 1973) but the case studies demonstrated activities being undertaken to transform intangible attributes into measurable entities; e.g. the use of assurance programmes to create trust in products and their production system.

The ISC leverages the benefits of three data systems (Livestock Production Assurance programme, National Vendor Declarations and National Livestock Identification System) to ensure a safe and traceable product that can be is being offered to customer and consumers, in addition to traditional quality parameters such as meat eating quality. Overall, traceability is being added to the suite of quality parameters that Australian red meat producers offer. Despite the acknowledged barriers to adoption of technologies by the ISC, the change that is occurring at the supply chain level, rather than at the organisational level, is encouraging as Denis *et al.* (2020) suggest that this a key ingredient to overcoming adoption of digital innovations.

The WAPC is a producer-owned co-operative. It is a much smaller entity than the ISC but it provides important insights into what is possible in terms of creating value through product quality and digital agriculture. Greenville *et al.* (2020) advocated achieving competitive advantage through value creation of commodity products and suggest the future is bright if product quality and reliability can be achieved. Creating value through the provision of trust in red meat quality is at the forefront of the ISC's agenda and the WAPC is no different. Digital systems are being adopted by both small and large entities alike in Australia's red meat supply chain but what separates the WAPC from the ISC, other than scale, is its supply chain design to reduce costs through its use of digital systems. It has long been recognised that cost reduction is a key criteria for supply chain design (Beamon 1998). The case of the WAPC demonstrated that a small group of farmers can re-design a supply chain to achieve cost minimisation and off-set disadvantages of the change by assuring product quality through a digital system.

The value created by farmers through good animal welfare practises

Animal welfare was specified as a valuable attribute in two of the three case studies. Digital technology is anticipated to facilitate product traceability of product, hence value. In the case of sheep eID, technology was viewed as a necessity to address historic problems. Whether good animal practises have become a selling point for livestock supply chains (Rushton 2011) or there is legitimacy in the knowledge that particular consumer groups are willing to pay a premium for high welfare of livestock (Lagerkvist and Hess 2011), the ISC and WAPC are transparent in their application of digital technologies to substantiate claims of high animal welfare practices in Australia. Animal welfare is now a component of the overall definition of a quality product and henceforth of value creation.

Value creation through good animal welfare practises also appears in the form of risk mitigation; as recognised by Choe *et al.* (2009). Again, value is realised not in the form of revenue but managing the risks of catastrophic disease outbreak. Recall from the section on eID and the Australian sheep industry, that the digital monitoring of livestock movements through the NLIS was introduced to monitor disease incidents, with animal welfare being a positive outcome of the digital system. This suggests that market access is an important ambition of high animal welfare standards and there is a clear recognition that value creation is appreciated by farmers and their wider industry partners beyond the revenue it realises.

Digital technology supports novel innovation trajectories

In addition to these findings, there is an important theme is the role of digital technology to support learning, adoption of innovation and experimentation. Agricultural extension has long been considered a critical part of innovation and continues to be a powerful method of partnering digital technologies with agricultural practise (Nettle *et al.* 2018; Ayre *et al.* 2019). The changing nature of government supported agricultural extension services, particularly in Australia, has shifted the provision of advice from the public to the private sector with grower groups supplying farmers with information and advice (Marsh and Pannell 2000; Feder *et al.* 2011). The private sector has done well to service this demand; as evidenced by the growth of Western Australia's Grower Group Alliance (see https://www.gga.org.au/) that leverage the benefits of farmer networks for collective innovation, learning and problem solving discussed by Berthet and Hickey (2018). However, provision of information by the private sector, like farm consultants for providing extensions services, should be viewed with caution as is not a sustainable business model. This is because information is easily shared between those who pay for it and free riders who benefit without paying (Pasour 1981; Giannakas *et al.* 2016). As such, the provision of information and advice on a commercial, private basis will be limited.

Despite this conundrum, this WAPC case study reveals two important developments in the progress of networks for learning, adoption of innovations, on-farm experimentation and innovation trajectories as described by authors such as Ingram and Maye (2020), Baumber *et al.* (2018) and Berthet and Hickey (2018). Firstly, WAPC's farmer-owned and farmer-led structure is an example of a collaborative network, not only for value creation but for learning as well. The two smart farms are examples of the type of experimentation advocated by OFE where farmers conduct farm-scale experiments with the purpose of understanding farm-scale variation in new practises as opposed to variation in traditional, small-scale trial plots. In the sharing of new knowledge through the WAPC and improving farmer competence, a social learning process is taking place (Cook *et al.* 2013; Lacoste *et al.* 2022): innovations by the farmers, for the farmers (Baumber *et al.* 2018). Secondly, the concept of agricultural extension has gone further than the support of a farm adviser to facilitate adoption (Llewellyn and Ouzman 2014) to encompass on-farm service support in the digital transformation process (Fiocco *et al.* 2021) and innovation trajectory (Ingram and Maye 2020). While learning is a key element in the WAPC's business model, some of the technologies that are being trialled and adopted are so complex and have such high-stakes that on-farm support is needed for adoption not to fall victim to the various phases of dis-adoption described by Montes de Oca Munguia *et al.* (2021). An example of this high-stakes technology is the adoption of digital operation and monitoring of livestock watering points. While the technology is available, there are significant negative animal welfare implications if the technology fails, which is a risk during early adoption. As well as providing ideas about technology and on-farm implementation, WAPC's access to a Smart Farms Co-ordinator is again acknowledging the complexity of agricultural innovations and the risks that they involve as well as engaging in a social process of broad-scale learning with farmers.

Conclusions

Value creation through traceability is an essential source of competitive advantage to the Australian livestock sector, which is reliant on trade because of its massive surplus of meat produced. But Australia cannot compete on price or supply capacity alone, so product quality is the only attribute on which Australia can compete in the global market for red meat. Quality is almost certain to become more important as the demands of international customers – who are willing to pay for high-quality red meat – continue to grow.

The process of traceability is supported by digital technology in several ways. Electronic ear tags used in livestock (see Fig. 1) facilitate the collection of essential supply chain data. This technology, however, cannot create value in isolation or in an environment of sporadic adoption. In complex food supply chains such as the Australian red meat sector, stakeholders are mutually dependent in their ambition to meet consumer demand. Data platforms, built on sound governance and intellectual property systems, are necessary for the responsible exchange of data through the supply chain, as is the engagement of multiple partners. Value is created only when data are shared and used for improved decision making. Continued learning and engagement identifies continued opportunities for value creation. These lessons relating to value creation from shared, digitised supply chain data and continued learning are likely to be the most important conclusions for this journal's usual readership: scientists in agronomy and plant sciences. This paper is asserting the benefits of digital collaboration and while it is focused on livestock supply chains, the principles of value creation through collaboration and governance are applicable to data scientists, behavioural scientists and biological scientists working in agriculture and agribusiness. Digital agriculture has opened up many aspects of the food system for change. We have demonstrated that the technology enables connectivity between actors within food systems who were previously poorly connected. Such interdisciplinary connection can prove challenging to scientists within individual disciplines. But change is being demanded of those who can navigate across disciplines within food system. This is why Kane *et al.* (2019) emphasise the importance of organisations to overcome the technology fallacy. The process of change in digital agriculture is driven by value creation. Value creation, appropriation and sharing are socio-technical processes that interconnect different actors dynamically within food system in diverse ways. Again, the opportunity is there for discipline-specific scientists to bridge across to others to enable value creation to occur. This is new for many. As suggested in the section on digital agriculture supporting novel trajectories, the 'diffusion of technology' approach to innovation, in which external actors such as extension agencies are regarded as promoters of innovation, describes innovation processes in digital agriculture poorly. Klerkx *et al.* (2019) and Eastwood *et al.* (2021) among others explain that innovation processes within digital agriculture are complex, dynamic and adaptive. Scientists in agronomy or plant sciences clearly have a role to play to create what Douthwaite (2001) calls technological novelties that can be developed with innovation partners. These processes of innovation are not new to agricultural sciences, but digital agriculture emphasises their importance by opening up new opportunities for change.

As our case studies illustrate, the adoption of digital technology by innovative farmers at an industry level is a complex process that includes:

1. The change that the technology enables at the farm level, the organisational level and the supply chain level.
2. The value that these changes create, including its location in the supply chain and ownership of value.
3. The continued learning that gives rise to innovation.

The entire process is unpredictable because of the disparate attitudes of producers towards the technology and the complex nature of value creation and adoption. Policy can support the process but adoption occurs by individuals within supply chains who perceive the necessity.

We should therefore anticipate that while adoption of digital technology is inevitable for the industry to continue responding to international demand, the pathway for digital innovation within the Australian livestock system will be influenced by factors beyond the technology itself. The process is not only about the adoption of technology for value creation in one part of the chain but the *sustained* adoption of technology whereby uptake of digital technology is continual and Montes de Oca Munguia *et al.*'s (2021) dis-adoption is avoided through continued learning and development. The strategic implementation of service support, as was identified in the case study on the WAPC, has shown to be a key factor in ensuring sustained adoption of technology. The strategic implementation of service support is an organisational innovation in itself and here the shift to private enterprise has meant that non-government organisations are now leaders of farmer learning. In this paper, we have shown that the WAPC and MLA are fulfilling this responsibility in Australia's red meat sector. The overall objective is for the long-term embrace of technologies that will facilitate sustained value creation through Australia's red meat supply chain.

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Data availability. Data to inform the case studies within were sourced from the internet or various publicly available reports. In all instances, web links and references (supported by web links were possible) have been provided to the sources of each piece of data used to build the case studies within this manuscript.

Conflicts of interest. Elizabeth Jackson is a non-executive director on the board of Sheep Producers Australia (see: https://sheepproducers.com.au/); Australia's peak industry council for sheep meat producers. Simon Cook is a guest Associate Editor of Crop & Pasture Science, but was blinded from the peer-review process for this paper.

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