The 'Digitalisation of Agricultural Innovation Systems': Governing the DAIS and exploring the prawn aquaculture value chain

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Abstract: *The policy implications of cumulative innovation are essential to consider in order to mitigate risk and capitalise on opportunities as digitalisation transforms agriculture. One project that involves imagining the future of the sector and aims to develop the necessary tools and infrastructure is the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) Digiscape Future Science Platform (FSP). This paper explores the policy framework encompassing these tools and elucidates considerations for future governance in Australia. Conceptually, we draw on Agricultural Innovation Systems (AIS) theorisation in the context of implications of digital technological development on policy. Methodologically, we utilise exploratory interviews with project stakeholders and members of the prawn aquaculture value chain.*

We argue society is at a critical point in time when the implications of digital agriculture need to be considered at broader national and international levels. Questions around data privacy and ownership are prevalent in agricultural settings, although appropriate institutional guidance is lacking. Three propositions are made as a result of the analysis of scoping research involving participants and stakeholders in the Digiscape FSP. We suggest that agricultural industries stand to benefit from the 'Digitalisation of Agricultural Innovation Systems', what we metaphorically refer to as the DAIS, if forums for discussion and creation of appropriate policy and governance are enacted with emphasis placed on the underlying values of society-technology interaction.

Keywords: *Digitalisation; Agricultural Innovation Systems; DAIS; Digiscape; Australia; agricultural policy*

Introduction

Digitalisation is becoming pervasive in modern life and an increasing emphasis on the digitalisation of agriculture, both in terms of transformative potential and associated pressures, is evident in the foci of a growing number of major research organisations and organisational alliances (see for example; AgResearch Limited (2017), CSIRO (2017), Internet of Food and Farming 2020 - IoF2020 (2017), Digital Agriculture Convergence Lab (2017)). In each instance, the digitalisation of agriculture and associated technologies are argued to be aligned with both incremental productivity gains *and* transformational change in Agricultural Innovation Systems (AIS). We introduce digitalisation; examining why it has already had and will continue to have more of an impact on the agricultural sector; why the way in which a digital transition is facilitated has implications for policy; and, why it is of urgency to address.

Digitalisation involves the impacts of digital technology on everyday life – in societies generally, in interactions with our environment and in the functioning of economies – and is said to be one of the most significant trends globally at present (Leviäkangas, 2016). It has been argued that that there is no single definition for digitalisation, it rather encompasses growth in human-computer or human-information and communication technologies (ICT) interaction (Billon et al., 2010). 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; Wolfert et al., 2017). The most often cited current impacts of the digitalisation of agriculture tend to involve the uptake of precision agricultural technologies that broadly reduce costs associated with inputs or work to increase yield and/or productivity (Aiello et al., In press; Chen et al., 2015; Eastwood et al., 2017; Lindblom et al., 2017). For example, auto-steering tractors fitted with GPS units that utilise satellites to minimise overlap and driver fatigue in cropping industries, along with associated yield mapping and variable rate input application (Godoy et al., 2012; Zhang et al., 2015). Recent advancements have seen this technology applied autonomously, meaning the farmer is (technically) no longer required to spend hours in the tractor seat (Croplands, 2017). It has been argued that significant changes in agricultural systems have been facilitated by new digital technologies and the associated convergence of multiple advances including: real-time monitoring, big data, Internet of Things, machine learning, cloud computing, and so on (Wolfert et al., 2017).

We will examine implications for the adaptation of policy, particularly regarding who reaps the benefits of digital agriculture and who bears the costs; for example who is legally responsible for an autonomous tractor? This paper will begin to delve into questions around implications for policy and provide a timely contribution to social science in the digital agriculture space (Bronson and Knezevic, 2017; Leonard et al., 2017). We address calls for research, and the associated knowledge gaps, relating to the social implications of a digital agricultural future (Rissman et al., 2017) and an examination of the role of policy to both guide and be guided by the digitalisation of agriculture (Koch, 2017).

We define policy as the formal institutions determining the legislative foundation of decision-making in society, in terms of what is appropriate conduct, what constitutes productivity, what are appropriate externalities, who should bear the cost of externalities, and so on (Antoniades, 2003). Policy is arguably one of the most important drivers in terms of the acceptability of action (or non action) within a given community (Wilson, 2013). As such, our primary research question analyses the implications of the Digitalisation of Agricultural Innovation Systems (DAIS) on the policy context and explores how existing policy will influence the DAIS. The primary research question examined is: *what are the implications of the DAIS for policy contexts and vice versa?* The remainder of the paper offers a more thorough explanation of AIS theory and the choice of the DAIS metaphor is explained in further detail in the following conceptual framework, before the methodology, results, a discussion of those results, and conclusion follow.

Conceptual framework

This section frames the conceptual contribution of this paper in relation to existing theory. Primarily, we build upon AIS literature to offer a novel metaphor of a shift toward the DAIS premised on the simultaneous development of multiple large-scale publicly funded digital agriculture research programs. This is not to discount significant private investment in digital agriculture, rather the focus on some of the recently initiated and publicly funded research programmes provides a more relevant analysis for national policy discussions because these programmes are publicly, as opposed to purely commercially, motivated.

The study of AIS, along with the prerequisite application of innovation systems thinking to agricultural development, is a relatively recent research phenomena that has rapidly gained traction in both the developed and developing world (Hall et al., 2003; Klerkx et al., 2010; Klerkx et al., 2009; Knickel et al., 2009). Underpinning the study of AIS 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., 2014). In this context innovation refers to the creation of something novel, whether that be a product, process, practice or relationship (Turner et al., 2017). AIS thinking offers a broad portfolio of research approaches depending on the complexity of the problem being addressed, the stakeholders involved, and institutional settings. The innovation systems component of AIS also allows for conceptualisation around the multi-level perspective (MLP) of socio-technical transitions which has been found to be useful in terms of framing multiple lines of action research (Fuenfschilling and Truffer, 2014; Ingram, 2018; Paschen et al., 2017). This theory section examines how digitalisation fits into AIS scholarship, and unpacks the reasons why each novel digital technology should not be visualised as simply another individual/discrete/independent technological innovation.

The interactions between technological trends and the context within which they sit (for example institutional and policy environments) need to be assessed as AIS digitalise if they are to be fully appreciated. The DAIS will result in existential questions for agricultural stakeholders world-wide. Existing research has uncovered potential dichotomies of open versus closed data systems (Wolfert et al., 2017), examined the varying values of smart farming communities depending on their institutional context (Carolan, In press-b), and questions have arisen about process-driven scientific advancement co-existing alongside data-driven machine learning algorithms. Along with these contextual questions, it seems we are moving rapidly (in historical terms) toward what once seemed like science fictional realities, for example fully automated (or farmerless) farms (see Oluboyede (2017) for one example).

The digitalisation of agriculture, through a variety of converging technologies, is creating landscape scale questions that have the potential to lock agricultural systems into pathways with increasingly unclear consequences (Digital Agriculture Convergence Lab, 2017). We argue that there are broader landscape and regime level (in MLP terms) lines of questioning underlying the DAIS that elevate above individual niche innovation. There is a lack of programme level analysis/synthesis of new technologies and a tendency to focus on individual technologies and other defined boundaries meaning broader analysis will help in more strategically guiding the DAIS socio-technical transition (Eastwood et al., In press; Fuenfschilling and Truffer, 2014).

Locating DAIS research programmes

Fig. 1 represents examples of three large digital agriculture initiatives in an attempt to highlight how industry based niche innovations form the majority of the applied research work currently underway. The broader questions around data ownership, information access, power relations, meaningful agricultural activities, open or closed networks, and so on are framed by the research programmes and associated regimes and landscapes within which

they sit. The DAIS metaphor also aligns with the rapid prioritisation, or holding up, of digital agriculture initiatives in not just the three research programme examples in Fig. 1 but elsewhere, with the push to find space and become a player in the digital agricultural game evident across the globe (Bronson and Knezevic, 2016; Carolan, In press-b; Walter, 2016).

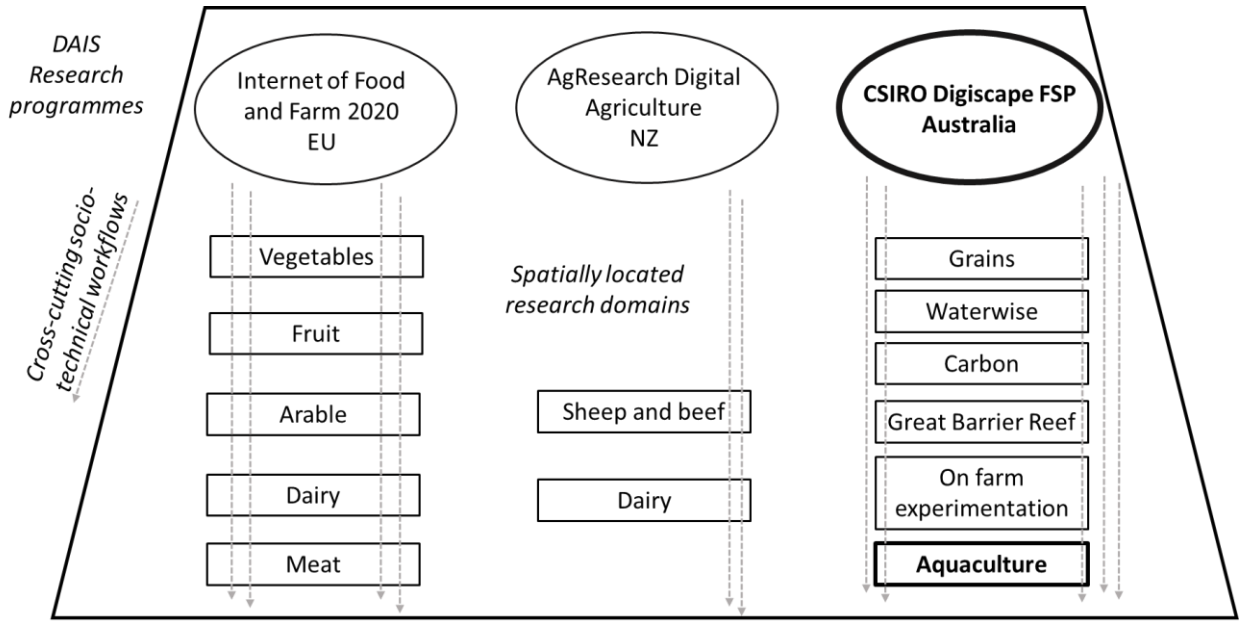

Fig. 1: Three research programmes attempting to capitalise on the Digitalisation of Agricultural Innovation Systems (DAIS) and their components as reported on respective web pages (AgResearch Limited, 2017; CSIRO, 2017; IoF2020, 2017).

*Note: the particular research programme (Digiscape FSP) and case study domain (aquaculture) focused on in this paper are highlighted in **bold** text.*

In terms of conceptually framing the DAIS, an interesting (and possibly contradictory) point in regard to each of the three digital agriculture research programmes are the multi-pronged and ambitious aims (Schut et al., 2016; Turner et al., 2017). While of obvious importance for funders, all three innovation platforms espouse a simultaneous focus on both incremental and transformational innovation in the agricultural sector (Nagji and Tuff, 2012). For example, the CSIRO (2017) Digiscape Future Science Platform (FSP) initiative aims to both *support next generation decision-making* and *transform agricultural industries and environmental* outcomes. The IoF2020 (2017) initiative is argued to have *revolutionary potential* to increase the *sustainability of value chains* yet another priority is that *efficiency is optimised.* The AgResearch Limited (2017) Digital Agriculture initiative aims to both *identify the barriers to taking up new digital technologies on and off farm* and *develop a technology roadmap to support the industry's transition,* assumedly toward the DAIS. While a number of other digital agriculture or smart farming research programmes could have been included, the aim of highlighting the three in Fig. 1 is to visualise the converging technological development elevating the DAIS beyond niche level outcomes.

While each of the aformentioned research programme aims are challenging in their own right, in many cases the core values underlying incremental productivity or sustainability gains versus transformational or systemic changes might be directly at odds and involve very different innovation capabilities and capacities (Turner et al., 2017). Transformational aspirations in terms of productivity and sustainability may be well-meaning but underlying these transformations are agricultural (and societal) values that need to be determined, articulated, reflected on, and will evolve over time with the acceptability (or not) of individual digital technologies (Eastwood et al., In press). The sub-sector foci of the respective research programmes is also a common feature and such an approach to research needs to be managed to avoid exacerbation of scientific silos (Polk, 2015). For example, the addition of cross-cutting research workflows increases the likelihood of network development within

the project teams with brokers likely to spread lessons to other project teams (Boari and Riboldazzi, 2014; Klerkx et al., 2012a). The subsequent method and results lead to a discussion of the potential implications of the DAIS on agricultural policies that formally dictate agricultural system boundaries, along with the associated informal institutions, attitudes and norms.

What is the Digiscape FSP?

The Digiscape FSP investment is led by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) and aims to *harness the digital revolution for farmers and land managers* (CSIRO, 2017). This challenge is addressed through use case applications of digital technologies in industry based projects along with cross-cutting socio-technical work flows that simuiltaneously develop common digital infrastucture for use into the future. As such, the Digiscape FSP is one of the research programmes fostering a transition toward the DAIS. Each of the Digiscape FSP use cases could be conceptually linked to niche level digital 'innovation ecosystems', interacting amongst relevant individual networks whilst also contributing learning across innovation ecosystems and up to the regime level through programme level learning and technological development (Walrave et al., In press). Importantly, as recently recognised elsewhere in the energy sector, both human and technological actors interact in these innovation ecosystems (Kolloch and Dellermann, In press). For the remainder of this paper we focus on human actors perceptions across and within these developing digital innovation ecosystems to determine both use case and regime level implications.

Methodology

The primary contribution of this paper involves the iterative research that has been conducted within the CSIRO future orientated digital land sector programme, the Digiscape FSP. Our analysis involves a multi-level approach with in-depth interviews conducted at the research programme (FSP) and niche application domain (use case) levels (Kläy et al., 2015). As this paper is reporting on an innovation platform that is currently in the early stages of development (*ex-ante)* our methodology can be considered a form of initial project scoping to serve the purpose of both contributing reflexivity to the action learning within Digiscape, as well as reporting thematically on systemic change (Beers and van Mierlo, 2017). This aligns with what Pant and Odame (2017) describe as reflexive process monitoring to combine elements of reflexive monitoring in action as applied social science (Fielke et al., 2017; van Mierlo et al., 2010). As such, and despite the limitations involved, we have applied a multi-level case study approach whereby we conducted interviews with 16 key individuals involved with the Digiscape FSP (Yin, 2014).

To delve deeper into the perspectives of industry we also examined one of the value chains that is the focus of an application domain, in the prawn aquaculture industry. The prawn aquaculture value chain is a unique example of a young industry with different drivers to more established Australian agricultural industries such as the cropping, beef, sheep, or horticulture sectors. We interviewed 8 individuals from various points of the prawn aquaculture value chain in order to both provide information back to the Digiscape FSP aquaculture project team and build broader innovation platform awareness. In total 24 semi-structured interviews were conducted from August to November 2017, whereby individuals were asked to varying degrees about their experience with digitalisation and the implications of technological innovation on policy and more broadly on the industries they were involved with. By analysing the perceptions of key individuals involved with this Australian research programme, and stakeholders along the value chain in one of the use case industries involved (prawn aquaculture), we offer a novel conceptualisation of the DAIS.

Contacting the key individuals working in the Digiscape FSP research programme was relatively straightforward due to an awareness on behalf of the authors of their collegues involved; the prawn aquaculture interviews proved more difficult. Snowball sampling was used to garner the perceptions of at least one individual at each point of the supply chain

adjacent the prawn farm (see Fig. 2) (Bernard, 2000). This involved enquiring at the end of each interview whether the interviewee was aware of anyone either side of them in the supply chain that might be interested in being interviewed, after which they either provided contact details directly or via email. Each of the 24 interviews went for between 30 and 60 minutes and were subsequently professionally transcribed. The resulting data were divided into key themes following a two-stage thematic analysis and subsequent workshopping of the findings within the 'Social Dimensions of Digiscape' project team (Thompson et al., 2017).

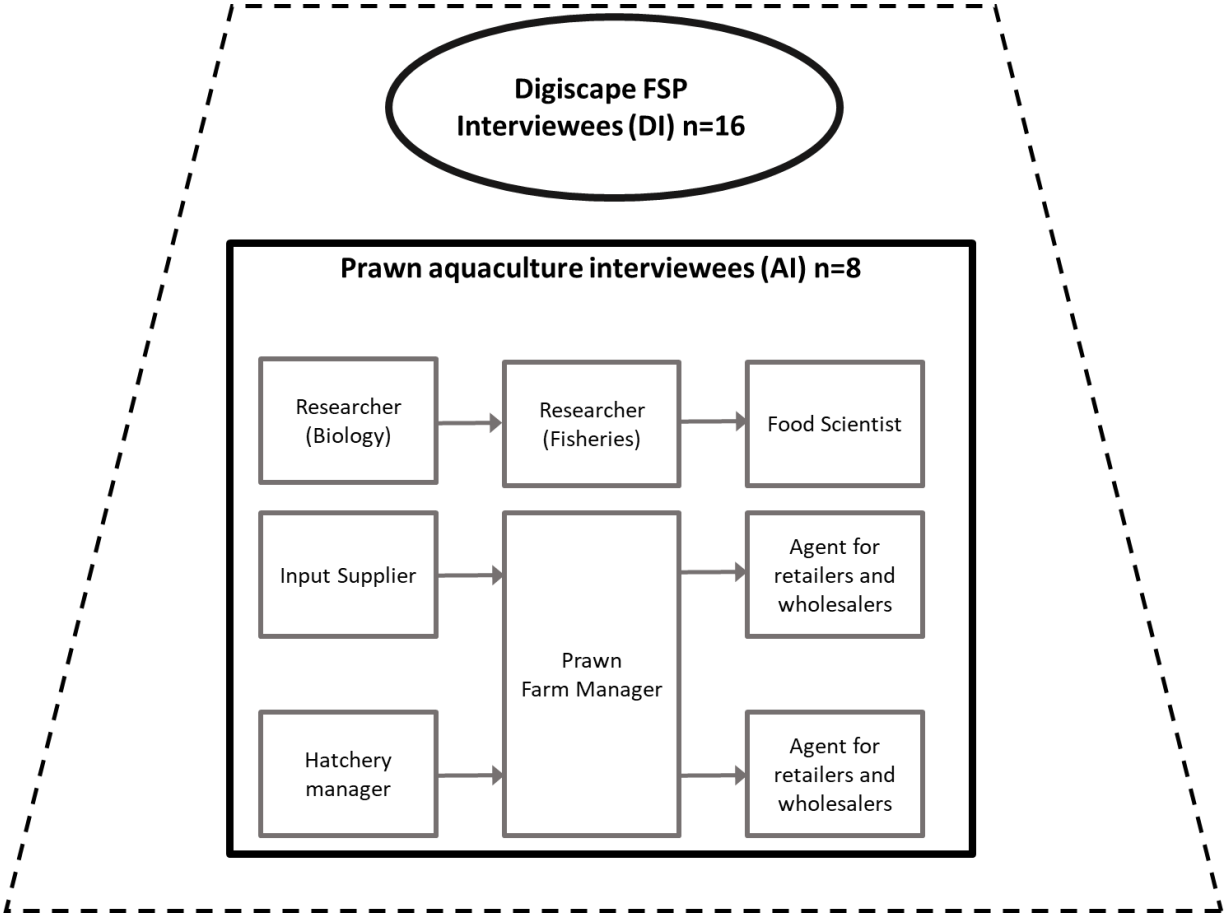

Fig. 2: Snapshot of the Digiscape FSP research programme and prawn aquaculture supply chain interviewees (codes DI and AI refer to Digiscape Interviewees and Aquaculture Interviewees respectively in the quotations that follow).

*Note: the Digiscape FSP and aquaculture domain remain in **bold** text and the permeable boundary indicates external influences can penetrate specific research programmes and project activities.*

Results

The results are structured in five sections whereby the first three include data from the Digiscape FSP interviewees in an effort to understand policy relevance generally, the uncertainty around policy in relation to the DAIS, and the identification of social learning in regard to what the policy implications of the DAIS meant for respondents. The final two sections shift to include data from the prawn aquaculture interviewees, with particular relevance to policy and finally the digitalisation of the industry more generally.

Policy relevance to the Digiscape FSP

There was broad recognition that respondents were familiar with policy within the context that their research projects, as part of the broader Digiscape FSP, operated. For example, recognition of state and national policy relevance of research outputs was explicit:

> The science that comes out of the project could inform water quality policies and regulations. We might find that things are not as bad as people thought or things are a lot worse than people thought (DI3).
>
> Where we would like to feed into national policy is ultimately to do multi-year climate forecasts. The big issue with multi-year climate forecasts is drought. That's what has the big impacts when it comes along (DI9).
>
> So in Australia it is more around trying to improve access to technology to improve profitability. At the Australian government level they are interested in the trade perspective of what the sectors are producing and how much, policy flows off that (DI1).

Specifically, in relation to the prawn aquaculture value chain that informs the later case analysis, an interviewee made links to development within the industry as a result of their previous experience:

> We've identified that there's this great opportunity for expansion [of prawn aquaculture] but partially it hasn't happened because of policy around granting leases. Policy and our outputs might be linked because what we are hoping to do is to facilitate - to remove some of the barriers for expansion (DI8).

In one case there was explicit recognition of the higher level international policy implications of project impact:

> Carbon is totally tied in with international policy, the opportunity we can create to generate low cost carbon [abatement] will profoundly shift the way Government sets its national indicative targets under international treaties, and that will have a role in how Australia negotiates international policy on climate... so by creating through carbon markets those opportunities to drive abatement, build livelihoods or social outcomes and drive environment outcomes, we can create opportunities (DI14).

These comments indicate that current and future policy settings need to be considered in order for at least some of the research projects within the broader FSP to maximise their impact:

> We've pretty much designed ourselves to live in the current policy settings and be robust to changes in those policy settings in two, three years' time (DI5).

Taken together, the policy environment within which the research projects were embedded was seen to be critical to the success (or not) of the resulting niche innovation/s. Elevating to the regime level, particularly in terms of the implications of digitalisation on agriculture, resulted in less certainty.

Practical uncertainty around implications of the DAIS on policy

While there was recognition, where relevant, that policy settings would influence the impacts of individual research projects and vice versa, the broader discussion around digitalisation and directionality of the policy/research relationship was more ambiguous. For example, the following statements indicate a lack of certainty regarding how policy would be affected:

> Now quite where the intersections of the social and the technical with the policy are I don't have a line of sight to. That's an interesting question (DI5).
>
> So whether the project drives policy or policy dictates success - long term success of the project - I'm not sure about (DI7).

Even when there was certainty around there being an impact on policy in the digital agriculture space there remained gaps in terms of exactly *what* these impacts might entail:

> Yeah, certainly, definitely we'll be having policy... something to say about the agricultural data/digital context... [and implications for the] policy landscape (DI2).
>
> The more that we try to implement policy around data and those sort of things - I think that's often an excuse to give it a go and try to sort through those things... who is using and who is actually accessing data (DI10).

In one rather developed sector case, however, the interviewee envisaged the implications of the application of their project:

> But at the Federal Government level, we will be able to provide far more timely information about agricultural production, [more so] than ever before. That means it could have impacts on how drought funding is distributed (DI12).

So while policy was widely recognised as aligned to research outcomes, and in many cases explicit links to policy impacts were made, in terms of actually envisioning outcomes only one stakeholder had imagined how their project would influence drought funding policy in Australia. Due to the relatively developed nature of the project where there were clear policy implications, it could be argued that actual implications of the other Digiscape research projects on policy (and vice versa) will develop over time. The uncertainty regarding impacts on policy was further evident when respondents reflected on the implications of digitalisation and the agricultural systems they were embedded in.

Reflective uncertainty around implications of the DAIS on policy

In questioning researchers on the policy implications of their work, the broad uncertainty in the following two cases was linked to a lack of individual expertise in the policy arena (italics emphasise *individual reflections*):

> There's obviously policy angles around that. *But I don't really - it's not something I've thought about* (DI13).

> *I don't know anything about policy around data ownership. So I have no idea* if we're going to be having an impact on that (DI3).

Similarly, there was also conscious recognition of thinking about implications for policy, but an in-depth understanding of those considerations were not the role of the researcher in question:

> Yes I have thought about it at a policy level. But *I am not a policy wonk and nor am I driven by it* (DI12).

Taken further, two interviewees provided thoughts that suggest their ontological drivers are being questioned by digital technologies:

> [Are we just] collecting more information or do we change how we operate on the land? That's where I don't know (DI1).

> I think one of the concepts I've certainly been listening too a fair bit is you've got to give up something to get something back. We don't seem to be uncomfortable in terms of every time we use our phones we're probably giving up something about ourselves, and the way we go about doing things in the agriculture sector I think they haven't quite grasped [those data privacy issues might be coming] (DI10).

The Digiscape researcher interview data suggest that while there is uncertainty around the extent or directionality of the policy implications of the DAIS, there was recognition that there would be ontological implications for the researchers and their projects. Understanding and becoming comfortable with the unknown*,* in policy forums and beyond, will become increasingly important in order to strategically manage niche innovations to influence regimes and landscapes (Hermans et al., 2013). This argument supports existing scholarship concerning the importance of being able to embrace the unknown in multi-inter-transdisciplinary research programmes (Bammer, 2012; Fleming and Howden, 2016).

Policy influence on prawn aquaculture

To add value to the analysis beyond the Digiscape research programme, the following two sections delve into a particular research project, with perceptions of stakeholders in the prawn value chain gathered as a baseline on the relevance of policy in the industry (more generally), and current and future digitalisation implications. In terms of policy, perceptions varied from negative impacts on the industry to more nuanced understandings of the benefits of regulation for stakeholders involved in prawn aquaculture. Negative comments revolved around the fairness of pollution discharge policies, particularly when compared to more established agricultural pursuits:

> It's something that the prawn farmers feel very deeply, in that everyone thinks that they're destroying the world... nobody alive today had a grandfather who was a prawn

> farmer. And so all these other industries, they're part of the national psyche; we've never questioned them. And yet a new industry comes along and is easily picked on (AI1).
>
> It was so ridiculous at one stage, that they were proving that water coming out of the farm had better quality than water coming in. It was, no, we want the same as what's coming in (AI4).
>
> It's just ludicrous the discharge conditions that we have got and they vary from one farm to another and it just hog ties the industry when you have got sugar cane, cattle properties that are putting out far more (AI8).

As well as discharge restrictions the multiple government departments (federal, state and local) having requirements for prawn farm development and operation also contributed to frustration:

> Do you really want us to develop or do you not want us to develop, because one agency is telling you to develop but other agencies are trying to block us everywhere they can (AI8).
>
> The expansion of the industry is hugely restricted by government policy, particularly because you've got different levels of state and federal policy interacting and then overarching organisations doing things completely differently (AI2).

Whilst negative sentiment exists in respect to the policy requirements to develop and operate a prawn farm, the benefits of such restrictions for the industry were also recognised by interviewees:

> It is an advantage for our industry to have good regulation because it protects that clean green image. It's not easy to grow prawns but a risk would be that if a dozen companies decided to do what we're doing and all of a sudden there was 10 times the product dumped on the market, we would have issues with price and supply or demand (AI3).
>
> You don't have to walk far to get primary industry being critical of government regulation. I think they'd much prefer to have this regulated environment than have the seemingly unregulated environment of prawn farms in south-east Asia; I can see the benefits from a biosecurity level (AI8).

Of particular relevance to this paper, in terms of links to AIS thinking, one interviewee considered policy to provide an innovation imperative:

> Applying regulations to an industry gives them the emphasis to innovate to work around it and to come up with new techniques for processing water and so forth. So that's actually the strength of the industry in that by forcing them to do it they will actually do it... so we end up with all the new industries being quite sustainable and yet the ones that we've got, because it's established practise, because everyone has done it since their grandfather, we can't change it. And that's just the way the world is. And it's a difficult thing for government to deal with (AI1).

While there were both positive and negative views on the implications of varying levels of policy on prawn aquaculture, barriers to industry development were also noted to result in protection in terms of managing product demand and biosecurity.

Influence of the DAIS on prawn aquaculture

In regard to the implications of digitalisation on the prawn aquaculture industry interviewees were also both pessimistic and optimistic. For example, pessimism fell into the categories of a lack of value, privacy concerns, and environmental constraints. One interviewee was not at all convinced that the promise of digitalisation was living up to expectations:

> From our end we have looked at trying to automate our ordering and documentation procedures to simplify it all. It became impossible... Everything we do is electronic through the [retailers] system. They send us our invoice, we confirm it and we do a delivery docket and our invoice on their system. So the automation on that has been their end. But has it worked? They spend more time fixing the system than they do what it was like beforehand, to be honest (AI8).

Arguably, these perceptions indicate a weakness in the process of technological development whereby a lack of user-centred design can lead to the belief that the system would have been better off without any such alteration (Lacoste and Powles, 2016; McCown et al., 2009). There was also confirmation of data privacy concerns from previous work (Carolan, In press-b; Jakku et al., 2016), specifically in regard to taxation implications:

> I would doubt that [prawn farmers would be open to sharing data] completely, because simply the fact that you have got farms that have got one or two sites or more and if you have got a public view on all of that, including the Australian Taxation Office... it will make one farm look like he's made an enormous profit and a loss on the other one isn't going to be connected... It is still farming and to have that sort of visibility I think would be quite dangerous from their point of view (AI8).

Of further significance in terms of reasons digitalisation may not have a major impact on prawn aquaculture were the environmental constraints of prawn farms. The corrosive saltwater along with the humid and stormy spatial locations which were required in order to maintain high enough water temperature all year round were seen as barriers to investment in *in-situ* digital monitoring technologies. Connectivity was also seen to be a barrier:

> The use of iPads and phones we have at the ponds to do real-time data input. Wi-fi is a bit of an issue as far as salt water and corrosion and what not, so real-time monitoring, sending information back via Wi-fi is still a little bit of a challenge, more an environmental challenge rather than technical challenge (AI7).

> There's not a farmer's management system in operation anywhere I don't think, but they're probably thinking about it. I guess that gets onto the next question of how feasible it is to install these sorts of things in a fairly hostile environment (AI1).

While the existing reasons digitalisation may not dramatically alter the prawn aquaculture industry were obvious to some interviewees, there was also recognition that digitalisation was coming to the industry, and in some instances was already present. The following four interviewees described digital technologies already improving the efficiency or productivity of their agricultural endeavours:

> Everything runs through a [digital] accounting system, we sell our feed through our website. We're looking at the solutions for a customer portal. Where people log in and are able to see what feed is what, where it's at, we're working on a lot of those kind of things but it's a slow process (AI2).

> Just speaking about our business it's quite advanced in that regard. So not just the admin side of things but also our production is virtually all digitalised these days. So things like feed monitoring, water quality monitoring, and feeds are done via machines that can be downloaded or done by iPads. We have a company server so all the information's stored and is accessible centrally. There's room for making it more advanced digitally. For things like 24 hour a day remote monitoring. We're still in the R&D phase of that one but virtually everything we do these days is done digitally rather than on paper (AI4).

> We have a product tracing program so everything's barcoded and scanned and stored and the same when it goes out so that when it goes to the customer, everything's traceable, digitally (AI5).

> We have even started to use a lot of data now to do modelling. The farm guys use their daily data to do real-time modelling on when to harvest to try and predict two, three, four months down the track when they should start harvesting to optimise profit. So, whether they start pulling out prawns that are smaller in size and let the rest grow up or let them stay in the ponds for a larger size before they start harvesting (AI7).

Along with the digitalisation already present there was also recognition that there was a drive to increase digitalisation of the prawn aquaculture industry, coupled with excitement about what might be possible in the not-too-distant future:

> I think farmers are trying to push for better ways to have their data captured and stored because at the moment I think it just relies on people's memory to record the data in these areas (AI6).

> There's a lot of appetite for that in our team here but it's just resourcing it and making it work right. But there's a lot of people doing those kind of processes already (AI3).
>
> If we can use real-time monitoring to measure eight, nine different parameters and then have some advanced modelling to interpret all those data and the trends then I think that can be extremely powerful and certainly be one of those quantum leaps forward. I think really understanding the fine relationships between all the different water body parameters that might be otherwise overlooked just through lack of time or from the complexity of the data (AI2).

The above findings suggest that to date policy within the industry is both a hindrance and beneficial and that despite some disagreement, further digitalisation seems to be inevitable, with associated increases in efficiency and productivity articulated. The results raise some key discussion points surrounding the DAIS and considerations for policy more broadly.

Discussion

Digitalisation in the prawn aquaculture value chain

Interviewees from the prawn aquaculture value chain discussed productivity gains that were possible with the increasing digitalisation of a relatively new industry in Australia. While there was mention of cases whereby technological advancements had reduced the efficiency of movements through the value chain, the potential beneficial outcomes of digitalisation seemed to be obvious to individuals at each point of the chain. These perceptions support the propositions and existing assumptions that digitalisation can contribute to industry economic growth and systemic change into the future (Leonard et al., 2017; Walter, 2016; Wolfert et al., 2017).

A critical examination of the interviews also indicates that there were no significant concerns around the need for policy to develop alongside digitalisation, policy discussions focused on the hurdles in place to start a prawn farm and more practical concerns. For example, the duplication of bureaucratic processes was found to be frustrating, although there was some understanding that policy acted to protect commercial interests, such as during biosecurity outbreaks and for supply management. In this case, industry discussions around the governance of digitalisation moving forward were immature (Leonard et al., 2017). More nuanced views of the implications of digitalisation were elucidated above this specific industry-level project.

Implications of the DAIS for governance in Australia

Digiscape interviewees more explicitly recognised the link between technologically driven change through digitalisation and appropriate governance than in regard to the prawn aquaculture interviewees. For Digiscape interviewees, however, there remained questions around the mechanisms that might appropriately facilitate digital agricultural development. These results further support arguments that (at both the niche and broader regime level) digital agricultural governance is in an immature state in Australia with uncertainty around potential implications a common theme throughout interviewee responses (Leonard et al., 2017). Comparatively, lessons from the Australian experiment in the DAIS will have implications for other agriculturally competitive export nations with minimal trade barriers, for example Canada, New Zealand and the United States of America. Each of these regions, along with rather different agricultural regimes (the EU or developing world for example), will individually determine the implications of the DAIS on their constituents. The diversity of actions, reflections, and adaptations throughout such a transition process, however, will benefit from lessons arising in other contexts. These findings also support arguments that the development of a *dedicated innovation systems* (DIS) research agenda, that moves beyond innovation for innovation's sake in an attampt to guide transitions in various places and spaces, is required (Schlaile et al., 2017). The cross-cutting research project this paper stems from will continue to consider leverage points to intervene in innovation applications as a priority moving forward.

Recent calls for a shift away from the over simplification of digital agriculture as a silver bullet to agricultural innovation espouse the need for responsible research and innovation (RRI) and appropriate governance in this context (Bronson and Knezevic, 2017; Eastwood et al., In press). Our analysis supports these calls, with reported uncertainty suggesting that engagement in leadership and governance of the DAIS will be critical in determining the outcomes for years to come. As Bronson and Knezevic (2017) explain, the ethical implications of power relations on data acquisition, citing the example of powerful social media companies, can determine who benefits as a result of data availability and analytics – with recent developments in the Facebook data sharing scandal one such example (Duffy, 2018). Digital governance needs to adapt to this rapidly changing space in the Australian context such that a discussion concerning how we distribute benefits fairly and equitably is had, contingent on value or productivity increases as opposed to legislative loopholes or rent-seeking behaviour of technological elite (Bronson and Knezevic, 2016). There is an urgent need to engage stakeholders in policy forums that consider the impact of pervasive digitalisation in the agricultural sector to gather and organise thoughts, co-develop approaches, and also inform them of developments in this space. Some of this work has begun in Australia (see Leonard et al. (2017)) but ongoing negotiation about what is or is not acceptable will be required in such a socio-technical transition. The ontological question regarding what it means to be productive is ambiguous when comparing the intangibility and ubiquity of some digital technological developments and the human need to consume and fuel ourselves with the product of agricultural enterprise (Carolan, In press-a; Fleming and Howden, 2016).

DAIS theorisation as a contribution to policy

The questions raised by conceptualisation and interogation of the increasingly influential DAIS will challenge existing agricultural policy infrastructure in ways that are unknowable, and as such recognition of the speed of transformation will require adaptive governance and guidance toward common principles (Chaffin and Gunderson, 2016). For example, the broad policy implications of data privacy are already front of mind in regard to international scholarship (Bygrave, 2014; Carolan, In press-b; Jakku et al., 2016; Rissman et al., 2017; Wolfert et al., 2017). There are three important propositions that are made on the basis of analysis of the results that combined help to answer the primary research question:

1) There is uncertainty around the broad policy implications of the DAIS - as such there is an opportunity to develop a shared vision for digital agriculture in Australia.
2) There is a need to engage agricultural stakeholders with policy forums to initiate discussions around appropriate facilitation of the DAIS.
3) The engagement and visioning processes will increase reflexivity and transparency regarding the implications of the DAIS.

To apply these findings to the conceptual contribution of this paper, DAIS theorisation can form a visual boundary object between niche innovation ecosystem domains and regime actors (such as policy-makers or broader governance stakeholders) as it helps explain the convergent implications of individual digital technologies (Jakku and Thorburn, 2010; Kimble et al., 2010; Klerkx et al., 2012b). Prompting discussion regarding the implicatons for society of the DAIS, and building on broader existential theorisation occuring elsewhere (Dunlop, 2016; Rifkin, 2013), Fig. 3 begins to visually articulate the implications of individual digital innovation ecosystems converging. As Tumbas et al. (Forthcoming) explain ’organi[s]ations need to *enact* digital practices, and do so by considering basic cultural elements, mindsets and rituals that characteri[s]e professional backgrounds involved in the process‘.

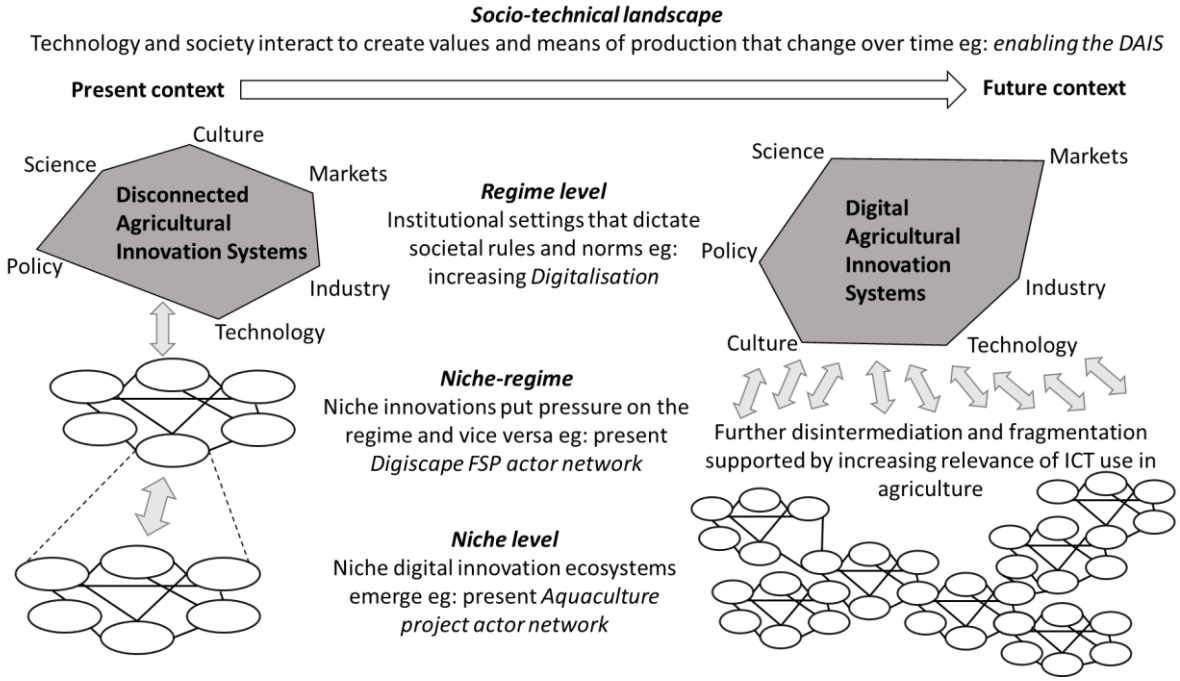

Fig. 3: Visualising digital innovation ecosystem interaction enabling the DAIS socio-technical transition.

Note: Individual nodes can represent both human and non-human (ie technological) actors. Fig. 3 was built by combining various concepts and does not predict either adaptation (maintenance of current institutional incumbents) or transformation (complete systemic alteration) at this point in time, rather the transition eludes to the increasing influence of human-digital technology interaction in the agricultural sector (Ingram, 2015; Ingram, 2018; Robertson et al., 2016; Smink et al., 2015; Walrave et al., In press).

Consideration of the rules that are set during maturing of the DAIS could introduce an experimental form of adaptive governance, possibly even utilising digital technologies (Chaffin and Gunderson, 2016). In the Australian context, work has already made explicit governance challenges created by the DAIS, with distinct recommendations around how to create the space for a more 'sustainable' digital agricultural future (Barry et al., 2017). Promisingly, there are significant parallel lessons that can be applied from the rapid evolution of AIS scholarship in the context of the DAIS, with innovation capacities and capabilities being transferrable to the context of the digital landscape, specifically the ability to experiment, take risks, and adapt (Turner et al., 2017).

We are at a critical point in time whereby the initial conditions of the DAIS are being arranged. As such, consideration of the drivers of digital technological development to influence agricultural land use need to be debated. In Australia, the future development of digital ICT will reshape production, values and understanding in the land-sector. If stakeholders are aware of the values and conditions prescribed by data underlying digital technologies, the technologies have the potential to be more transparent and trustworthy. While there is currently uncertainty around the real policy implications of the DAIS, particularly from those embedded in the agricultural research space, there is a need to engage with policy forums to determine the acceptability of human-machine interaction as machines begin to think, learn and make decisions from their own data-driven experiences through unsupervised machine learning (Brynjolfsson and McAffee, 2017).

Conclusions and avenues for future research

Analysis of such a limited component of the wider AIS does not acknowledge the various, simultaneously evolving, networks of actors in the digitalisation space. For example, this paper neglects the influence of the private sector on digital innovation in agriculture, where discussions of institutional power relations to digital technology implications are just as important, if not more so (Carbonell, 2015). In defence of this paper, however, is the use of an exploratory case study approach to scope in-depth initial perceptions on the originally

conceptualised DAIS in one Australian research programme. By limiting the scope of this work we will be able to monitor change in this particular network over time as the research programme, and other DAIS influences evolve.

Our contribution raises important lines of enquiry for future research: what are the policy implications of the 'digital divide' between rural and urban areas, particularly in regard to the uptake and relevance of the digitalisation of agriculture? What is the likely outcome of digital technological innovation in agriculture in the absence of appropriate policy to protect those at the production end of the value chain? Are there general principles that could be followed for adaptive policy in order to minimise risk in the agricultural sector in the face of rapid change? And, what are the ethical implications for action researchers (such as ourselves) in this digitally driven innovation space?

While this initial scoping effort determined that there is potential for the DAIS to create benefits for agricultural stakeholders, the management of values that underlie digital technologies will be critical to their uptake, acceptance, and ongoing use. By monitoring the evolution of the technologies that are created as a result of digital agriculture initiatives, it will be possible to track the characteristics of successful and failed niches over time. As such the policy environment of the regimes these niches are embedded in can become one of the avenues explored in future work as the DAIS continues, with feedbacks down to the niche level and up to the landscape level resulting in useful evidence to explain directionality of influence. While the convergence of digital technologies on agricultural and land based industries are exciting, and the associated possibilities for transformation and empowerment are recognised in Australia and around the world, it is important to strategically set up policy infrastructure to cope with these changes.

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