Journal of Rural Studies 55 (2017) 193–202

Contents lists available at ScienceDirect

Journal of Rural Studies

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

Ordering adoption: Materiality, knowledge and farmer engagement with precision agriculture technologies

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A R T I C L E I N F O

Article history:
Received 11 April 2017
Received in revised form
29 June 2017
Accepted 18 August 2017
Available online 31 August 2017

Keywords:
Adoption
Ordering
Materiality
Technology
Farming knowledge
Precision agriculture

A B S T R A C T

In their efforts to understand why and how farmers adopt new technologies, techniques and programmes, rural sociologists and geographers have typically focused on the social and cultural relations in which farming knowledge and practices are embedded. However, limited scholarly attention has been given to the important ways in which materials and materiality are a constitutive element in how farmers come to know and engage with technology. This paper addresses this issue through the application of theoretical work on ordering, which focuses on the materially heterogeneous processes and implicit strategies that hold together and perform particular social and organisational arrangements. Drawing upon qualitative data from a research project on adoption of precision agriculture (PA) in the Australian rice industry, we identify two principal modes of ordering: (1) *commercial-technological*, in which lack of compatibility between technologies produced by different machinery manufacturers creates challenges for farmers in integrating and adapting PA to existing farming practices and systems; and (2) *biophysical*, where drought and low water allocations create uncertainty and a reluctance by farmers to make large capital outlays for PA technology. While these modes of ordering constrain rice growers' capacities to adopt PA technology, we argue that growers also engage in their own alternative ordering practices to negotiate, work with, and work around these constraints. We refer to this work as *tinkering* and argue that it is a powerful, yet little recognised, form of ordering enabling growers to take advantage of the material benefits of PA in a way that is flexible, adaptable, and fits their immediate farming circumstances. In concluding, we contend that an ordering approach provides a fruitful way forward in recognising the more-than-cultural dimensions through which farmers engage with technology, and particularly the complex ways in which materiality intertwines with, shapes, and is shaped by, farming knowledge and practices.

1. Introduction

Rural sociologists and geographers have long argued that farmers' knowledge, and the broader social and cultural relations in which such knowledge is embedded, is crucial to understanding farmer engagement with and adoption of new programmes, techniques and technologies (e.g., Clark and Murdoch, 1997; Morris, 2006; Oliver et al., 2012; Riley, 2008; Warren et al., 2016). This 'socio-cultural' approach to knowledge has generated significant insights into making sense of why farmers might partially adopt or not adopt at all. It has also drawn attention to farming knowledge as a relational achievement; that is how farmers' tacit, experiential knowledge relates to and is integrated with other forms of knowledge (such as 'scientific' knowledge), and the consequences of these relations for programmes or initiatives seeking to change farming practices. However, in focusing primarily on the social and cultural relations that underpin farming knowledge, limited attention is given to 'knowledge in action' (Bruckmeier and Tovey, 2008, p. 321), that is, the ways in which knowledge, and the practices associated with the application of that knowledge, are a co-production of social and material products (Jasanoff, 2004). This

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http://dx.doi.org/10.1016/j.jrurstud.2017.08.011

paper addresses this issue by investigating the significance of materiality in how farmers understand and engage with technology.

Materials – which include human craftwork, texts, machines, markets, plant matter and animals – are a constitutive element of how farmers come to 'know' and engage with new technologies and techniques (Higgins, 2006; Legun, 2015; Singleton, 2010). However, their significance in the context of research on farmer adoption is yet to be explored systematically. According to Law (1992, p. 381), studying how these materials are organised and 'come to be patterned to generate effects like organizations, inequality, and power' is an important task for social scientists. Such a task involves identifying and examining the relations between different 'modes of ordering' – the combination of socio-materially heterogeneous processes and implicit strategies that give rise to particular social and organizational arrangements (Law, 1994; Mol and Law, 2002). An analytical emphasis on socio-material ordering, which we apply in this paper, builds on growing engagement with a relational approach in agi-food studies, which is characterised by attention to 'how materialities, practices and discourses matter in terms of their effects and affectivities' (Carolan, 2017, p. 136).

Drawing from a qualitative study of technology adoption in the Australian rice industry, this article investigates the modes of ordering that influence how growers come to know and engage with precision agriculture (PA). Broadly, PA refers to a range of techniques – such as yield monitoring and mapping, remote sensing, and variable rate technology – that utilise technologies including Global Positioning Systems and Geographic Information Systems. As a suite of technologies, PA is argued to contribute 'to the long-term sustainability of production agriculture' through more targeted and strategic use of inputs that 'reduce losses from excess applications and from reduction of losses' due to nutrient imbalances, weed escapes and insect damage (Bongiovanni and Lowenberg-DeBoer, 2004, p. 383). An ordering approach draws attention to the heterogeneous sets of relations and implicit strategies through which PA is enacted, without assuming that these relations are necessarily 'social' or 'cultural'. It also provides broader insights into the variously enabling and constraining effects engendered by these sets of relations. Based on our analysis, we identify two principal modes of ordering PA: *commercial-technological* and *biophysical*. We argue that while these forms of ordering have a generally constraining effect on rice growers' understanding of how PA can work for them, and their capacities to implement PA on-farm, growers also engage in their own alternative ordering practices – which we refer to as *tinkering* – to negotiate, work with, and work around these constraints. Tinkering is partly a consequence of the material constraints imposed by commercial-technological and biophysical modes of ordering. However, it is also a practical strategy for growers in caring for their farm as an economic and social unit (Krzywoszynska, 2016), which enables them to take advantage of the material benefits of PA in a way that is flexible and fits their immediate farming circumstances.

2. Mapping a socio-cultural approach: from values and motivations to 'knowledge-cultures'

While social science research on farm-level adoption is diverse, it is broadly united in taking a 'socio-cultural' approach – the recognition that social and cultural relations are fundamental to understanding farmer responses to new programmes, techniques or technologies. This literature can be divided into two related areas of focus: farmers' values and motivations, and the relationship between farmers' tacit knowledge and scientific knowledge. These are outlined briefly below.

Rural social researchers have been studying the role of values, goals and motivations in influencing farmers' adoption decisions since the 1950s (e.g., Gasson, 1973; Ilbery, 1983; Moon and Cocklin, 2011; Morris and Potter, 1995; Rogers, 2003). Early research by Rogers (2003) found that farmers with high levels of motivation are more likely to make the changes necessary to adopt an innovation, while Gasson (1973) found that farmers' intrinsic orientation to their work, underpinned by the high importance of instrumental goals, are central in understanding their adoption decisions. Scholars have since built on this research by seeking to identify farming values and goals across a range of geographic contexts and farming systems, and the implications for the design of programmes seeking to change specific aspects of farm practices and/or farmers' adoption behaviour. For example, Greiner and Gregg (2011, p. 264) found that farmers are 'motivated by actively pursuing personal and family well-being and make decisions within a care-based ethic rather than simply reacting to financial opportunities, imperatives and constraints'. Similarly, Bohnet et al. (2011, p. 635) argue that 'graziers are motivated by pursuing personal values', and policies and extension programmes are unlikely to be effective if they 'do not take graziers' values and motivations into consideration'. An important insight from this literature is that individual values and goals underpinning farm practices are located within broader farming cultures, providing farmers with a sense of meaning and identity (Burton, 2004; Burton et al., 2008; Sutherland and Burton, 2011). For example, Burton (2004, p. 210) contends that agricultural landscapes are 'highly symbolic environments where the social value of production must be considered on a par with economic value'. Particular farming practices generate 'symbolic capital and socio-cultural rewards' and are strongly associated with being recognised as a 'good farmer' (Warren et al., 2016, p. 179). Whether or not a new innovation or practice is consistent with notions of good farming therefore has a strong influence on farmer adoption decisions.

Recognising that farmers' goals and values are an important feature of broader farming cultures, social researchers have also examined the role of farming knowledge in the implementation of new practices, innovations, or government programmes. This literature broadly emphasises the need to understand and take into account farmers' tacit and experiential knowledge. Failure to do so contributes to farmers' loss of trust in scientific and government institutions and difficulties for authorities in achieving farmer engagement or adoption (Clark and Murdoch, 1997; Wynne, 1996). Farming knowledge is in some respects distinctive from 'scientific' knowledge (Murdoch and Clark, 1994; Winter, 1997). Yet, at the same time, the two forms of knowledge are related. As Riley (2008) argues, farmers are 'experts in their own fields' (p. 1288); their experience-led understandings and practices provide important insights into farm management, but these 'are often beyond the reach of techniques and records of elite science' (p. 1291). This relational approach to knowledge has increasingly informed social science research on farmer understandings of, and engagement with, programmes aimed at improving on-farm productivity or agri-environmental management (Bruckmeier and Tovey, 2008; Ingram, 2008a; Morris, 2006; Oliver et al., 2012; Riley, 2008). It is this approach to knowledge that we seek to build upon in this paper.

Applied specifically to PA, a relational approach to knowledge is best exemplified in the work of Tsouvalis et al. (2000) who use the heuristic of 'knowledge-cultures' to examine the merging and inter-mingling of different knowledge forms in the context of yield mapping (a technique of PA). The notion of knowledge-cultures recognises that knowledge is a relational achievement. It acknowledges 'the fluid and interactive nature of different ways of sense-making', the 'formative contexts within which meaningful, symbolic actions and knowledges are shaped', and 'the processes whereby the conceptual structures informing people's acts are negotiated' (Tsouvalis et al., 2000, p. 912). For Tsouvalis et al., yield mapping constitutes a particular knowledge-culture "which casts farmers as office managers rather than as cultivators and which portrays scientists and IT specialists instead of agronomists as increasingly important actors in the decision making process on the farm" (Tsouvalis et al., 2000, p. 913). Through a case study of two farming areas in the UK, Tsouvalis et al. show how farmers contest and negotiate this knowledge-culture by questioning: (a) the usefulness of yield maps – particularly their capacity to reveal issues with yield variability of which farmers were not already aware – and (b) the capacity of yield mapping to improve the accuracy of fertiliser applications, and enhance yields.

The heuristic of 'knowledge-cultures', and a relational approach to knowledge more broadly, is significant in highlighting the dynamic and fluid relationship between seemingly distinct forms of knowledge, as well as the ways in which farmers contest, adapt to and accommodate, different knowledge-cultures. From this perspective, farmers' adoption decisions are conceptualised as an effect of how different knowledge-cultures are constituted and relate to one another. However, to date the main emphasis has been on the *social and cultural relations* through which farming knowledge is produced and intersects with other knowledges. This overlooks the important ways in which knowledge building is a co-production involving 'the social dimensions of cognitive commitments and understandings … and the epistemic and material correlates of social formations' (Jasanoff, 2004, p. 3). Similarly, it also overlooks how (farming) knowledge, and the practices informed by and produced through that knowledge, is 'a product or an effect of a network of heterogeneous materials' (Law, 1992, p. 381). We argue that an analytical focus on 'ordering' enables identification of the socio-materially heterogeneous processes of co-production through which PA is constituted as an object of farming knowledge. At the same time, it provides insights into how the organisation or ordering of these materials imposes constraints while also generating alternative possibilities for farmers in making PA workable on-farm.

3. Ordering, farming knowledge, and technology adoption

According to Law (1994), *ordering* comprises three important analytical dimensions that make it different from the traditional sociological emphasis on social *order*. First, ordering recognises that 'orders are never complete' and that they 'are more or less precarious and partial accomplishments' (pp. 1–2). Second, processes of ordering are plural, co-existing with one another. This means there is no such thing as a singular or root order through which the social world can be explained. Third, ordering is not simply 'social'; 'what we call the social is *materially heterogeneous*' comprising 'talk, bodies, texts, machines, architectures' (p. 2, emphasis in original). Widely applied in science and technology studies, research using the notion of ordering has focused on the heterogeneous processes of assembling and dis-assembling through which phenomena such as bridges (Suchman, 2000), airports (Knox, O'Doherty, Vurdubakis and Westrup, 2008), subway signs (Denis and Pontille, 2015), biosecurity surveillance (Donaldson and Wood, 2008), and disabilities (Moser, 2005) are performed and held together. However, limited attention has been given to ordering in the context of agriculture and farming, particularly as it applies to farmer engagement with and adoption of technology. We argue that the analytic of ordering builds on and contributes to the literature on farming knowledge in two important ways.

First, it enables greater scrutiny of how materialities are involved in the production and application of farming knowledge. Rural studies scholars are devoting increased attention to the significance of materialities in the constitution of farming spaces and practices (Carolan, 2017; Higgins, 2006; Legun, 2015). Yet, there remains limited understanding of how materialities relate to and intertwine with farming knowledge, and the consequences for farmer engagement with new technologies. Actor Network Theory (ANT), the broader ontological approach in which the idea of ordering is located, is distinctive in taking a relational approach to materiality – termed *relational materialism*. As Law (1999, p. 4) notes, ANT takes the relationality of entities, 'the notion that they are produced in relations, and applies this ruthlessly to all materials'. This involves extending analysis beyond just human agents and 'social' relations to encompass heterogeneous materials in the patterning of the social.

An analytic of ordering also highlights the challenges posed by material relations and entities in integrating farming knowledge with other knowledge-cultures. The challenges involved in knowledge integration are well documented (e.g., Clark and Murdoch, 1997; Ingram, 2008b; Tsouvalis et al., 2000). Nevertheless, it is often assumed that these can be overcome through the development of programmes, processes, or decision-support systems that encourage farmer participation in knowledge building, joint learning, and the sharing of decision-making power (Bruckmeier and Tovey, 2008; Oliver et al., 2012; Raymond et al., 2010). From an ordering perspective, human agency, knowledge, and organisation is generated 'in a network of *heterogeneous* materials' (Law, 1994, p. 25, emphasis in original). Consequently, differences between knowledge-cultures, or a focus on knowledge as the main object of analytical attention, is not necessarily the main issue in understanding how to improve farmer engagement with, and adoption of, programmes or technologies. Greater scrutiny is needed of the 'heterogeneous assemblages of materials, technologies, and people' (Knox et al., 2008, p. 871) that comprise different modes of ordering, and how these 'work and relate in different ways' (Mol and Law, 2002, p. 7) to shape farmers' capacities as agents.

Second, much of the existing research conceptualises farmers as having a distinctive form of knowledge, or being located within a specific knowledge-culture (although see Morris, 2006). The fluidity of knowledge is recognised in principle, including the ways in which farmers negotiate different knowledge-cultures (Tsouvalis et al., 2000). However, farmers' engagement with new technologies and practices is viewed primarily as a product of their experiential/tacit knowledge and the farming culture(s) within which they are located. In contrast, the idea of ordering enables a focus on how farming knowledge and practices are a contingent effect of multiple modes of ordering that 'work in different ways to open up or close down possibilities' (Anderson et al., 2012, p. 172). While different modes of ordering may co-exist side-by-side, they can also, as Mol and Law (2002, p. 10) argue, 'overlap and interfere with one another'. This means, according to Moser (2005, p. 669, emphasis in original), that '*in practice*, people are not caught in any one mode of ordering', but 'rather slip and move between multiple modes of ordering that coexist, are partially related in complex ways, and even folded into each other'. As a consequence, even if the overall effect of ordering is to reinforce the dominance of particular actors or arrangements, there is always an openness to ordering that enables alternative possibilities for agency, identity and organisation to co-exist (Moser, 2005, p. 689).

In this paper, we demonstrate how materiality is constitutive in the ordering of farmer engagement with PA in the Australian rice industry. We build on a relational approach to knowledge, identifying two key modes of ordering – commercial-technological and biophysical – that shape how rice growers come to 'know' and engage with PA. In doing so, our analysis highlights the constraining effects of these forms of ordering for growers in integrating PA with their existing farming practices, constraints over which growers have limited control. Significantly, we argue that such constraints have little to do with differences in forms of knowledge or knowledge-cultures. They arise from the ways in which materials and material entities – software, machines and climate – are intertwined with 'social' arrangements, such as the commercial objectives of machinery manufacturers and government regulation of resource use. Drawing on Moser's (2005, p. 689) argument that 'there is an important form of openness in the material practice of ordering', we also investigate the alternative possibilities for rice growers in engaging with PA, and making PA technology workable at a farm-level. To date, ordering has been applied primarily at the meso-level of medium to large sized organisations and agencies (e.g., Knox et al., 2008; Law, 1994; K. Wilkinson, 2011a,b). Consequently, there has been limited analysis of how ordering works in practice at more micro-levels such as farms. Through the notion of 'tinkering' (Law, 2010; Mol, 2008), we show how the constraints posed by material modes of ordering contribute to alternative ordering strategies by growers in making PA technology consistent with, and workable within, their existing farming practices.

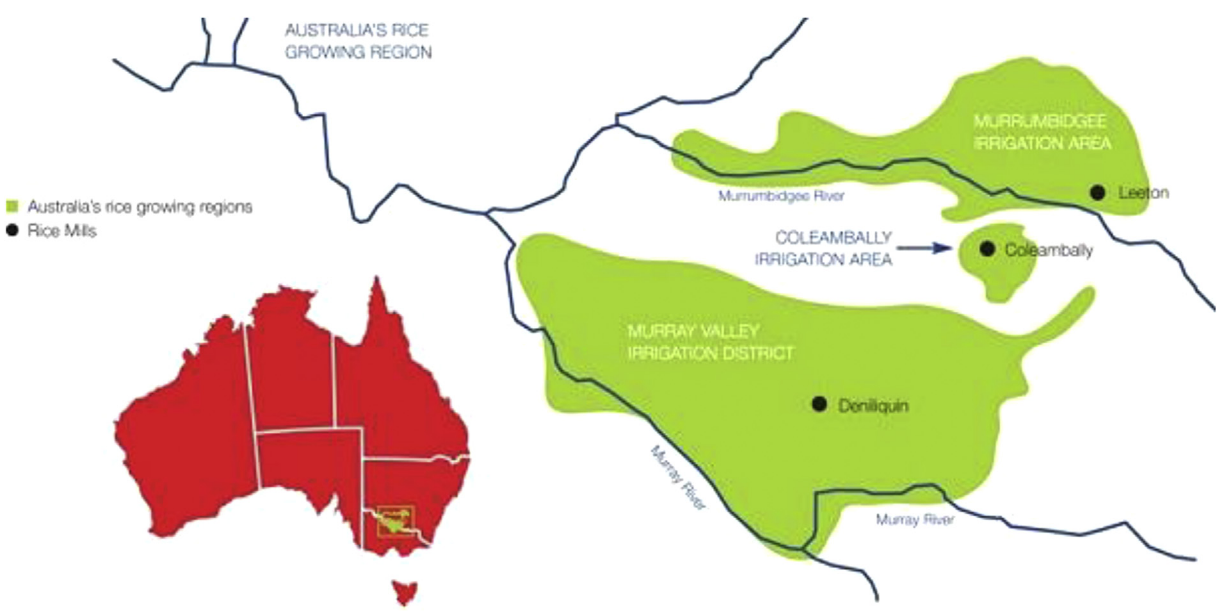
4. Context and methods

This article focuses on the Australian rice industry, which is located in the Murrumbidgee and Murray valleys in Southern New South Wales (NSW). Specifically, the irrigation districts of Murrumbidgee (MIA), Coleambally (CIA) and Murray are situated within this area (see Map 1). These districts are characterised by hot summers and cool winters. There are approximately 1500 farms across these regions, which are collectively capable of producing in the vicinity of one million tonnes of rice each year. Rice production is highly dependent on the availability of irrigated water and annual yield can change accordingly. Water available for growing is determined through a system of annual water allocation, which is managed by the NSW state government. Rice is generally grown as part of a rice-based farming system that can include irrigated winter cereals and canola, summer crops such as maize, soybeans and cotton, and irrigated pasture for livestock production. Growers in the region are also often involved in other types of farming including livestock, cotton, nuts or citrus.

The data discussed in this article forms part of a broader project funded by the Australian Rural Industries Research and Development Corporation (RIRDC). The aim of the project was to investigate the social factors that influence technology adoption by Australian rice growers, and how the industry can work better with growers to increase the effectiveness of technology adoption. Since the industry is seeking to promote wider uptake of PA by growers, this comprised a key focus of the research. PA technologies, such as auto-steer, variable rate application, and yield mapping have been widely adopted by farmers in the Australian rice industry. However, it is the quality rather than the rate of adoption that is the critical issue. That is to say, while farmers have been adopting PA technology, our early discussions with industry stakeholders indicated that many farmers were not taking advantage of the full benefits that the technology offers. For example, we were told by one stakeholder of a farmer who had installed yield mapping software on his tractor, but did not record the data collected. Such issues are recognised as a widespread problem by the industry, which received funding (also from RIRDC) in 2013 to engage and work with growers and agronomists to develop improved PA skills and knowledge across the industry (Precision Agriculture, 2014).

For our research, we adopted qualitative methods consisting of semi-structured interviews undertaken in two concurrent phases. In the first phase (March–April 2015), interviews were conducted with 20 key rice industry stakeholders, including farm advisors and agronomists as well as representatives from organisations involved in rice industry extension activities. The aim of the interviews was to understand the role that rice industry stakeholders and governing organisations can play in enabling technology adoption across the rice industry. Participation by stakeholders was considered crucial in providing information on current methods used to develop change strategies; how technological change is communicated and promoted; involvement of growers in change processes; key change priorities; perceptions of grower best practice, and limitations of current approaches.

In the second phase (April–September 2015), interviews were conducted with 59 rice growers from family owned or managed



Map 1. Australia's rice growing regions.
Source: Ricegrower's Association of Australia Inc. http://www.rga.org.au/the-rice-industry/rice-community.aspx

farms across the three main rice growing regions – Murray (25 interviews); MIA (25 interviews), and CIA (9 interviews). A purposive sampling technique was used to ensure that a diversity of enterprises and growers were represented. The aim of the interviews was to (a) identify the main constraints to grower adoption of technology, and the enablers that encourage late or non-adopters to engage in change practices; and (b) explore communication methods that growers used to become informed of changes in the rice industry as well as learn about new technology. Participation by growers was considered crucial in understanding their current use of technology; their awareness of, and the ways in which they receive information on, new technology; the technology that they see as most and least relevant to their farming practices; levels of support in adopting and using technology; enablers and constraints to technology adoption; and the input they have into technological change in the rice industry. Stakeholder and grower interviews were initially analysed using open and axial coding (Coffey, 2013; Miles and Huberman, 1994) as a way of firstly finding common descriptors and then the relationships around and between the different descriptors. We then analysed the data thematically (Patton, 2015) to derive key themes. The modes of ordering discussed throughout the remainder of this paper – commercial-technological, biophysical, tinkering – are three of the themes that emerged from the data.

5. Modes of ordering farmer engagement with PA in the Australian rice industry

5.1. Commercial-technological ordering

Growing dependence by farmers on the consumption of inputs promoted by corporate agribusiness is well documented in the agri-food studies literature (e.g., Almås and Lawrence, 2003; Magdoff et al., 2000; Wolf and Wood, 1997). This literature is largely informed by a political economy perspective, which conceptualises the profit-making interests of agribusiness firms as crucial in contributing to the commodification of field-level information and farming knowledge (Wolf and Wood, 1997). Similar to other new technologies, PA is argued to contribute to the intensification of processes that substitute capital for farmers' experiential knowledge, and, more broadly, 'diminish farmers' and public institutions' contribution to the production process relative to non-farm agribusiness' (Wolf and Wood, 1997, p. 203). Such processes are claimed to advance 'the interests of nonfarm agribusinesses within a rapidly restructuring agriculture' and further increase dependency of farmers on off-farm inputs (Wolf and Buttel, 1996, p. 1271).

From a political economy perspective, the objectives of PA machinery firms may be viewed primarily as a form of social ordering in which farmers, to remain viable, must become increasingly dependent on the commercial inputs supplied by these firms. Yet, such a view overlooks how the commercial objectives of machinery companies are performed in and through material forms. According to Law (1992), modes of ordering are more likely to last if they are embodied in durable materials – such as technological hardware and software. In the case of PA, multi-national machinery firms, such as John Deere, AGCO (manufacturers of Massey Ferguson products) and New Holland, are significant global players in PA and they perform their commercial interests through material forms such as legal and digital 'locks' on hardware and software packages (Carolan, 2016). Hence, the 'social' profit-making objectives of machinery firms come to be intertwined with and inscribed in the proprietary technologies they produce, which in turn gives those objectives material durability (Joerges and Czarniawska, 1998) – what we term a commercial-technological mode of ordering.

As our research shows, this form of ordering was viewed by growers as constraining their capacity to engage with PA, frustrating their efforts to take full advantage of the benefits of PA technology, and locking them into products that may not necessarily meet their priorities and goals. For example:

> One of the big detractors that I find about modern [PA] technology is that it's being ambushed by retailers, marketers, and it's not serving the purpose that we want it to be serving, a purpose that they've determined they can use …. It's manipulation of your communication device to help them sell stuff. And that becomes a marketing tool. (CIA, Grower 4)

> … a lot of the information that you generate from what you're doing is not just yours. The provider of the hardware and the software claim that to be their data as well, and I've got a real issue with that whether you should be able to opt out …. So, they're mining your personal information and the catch is that you can't use their technology unless you agree to it. So, I don't like that. [A particular machinery manufacturer] is in that space more than any of the others …. I'd be thinking long and hard about whether I purchased equipment [from that manufacturer] just because of the conditions that come with it. (MVIA, Grower 20)

From this perspective, the inscribing of commercially-oriented technical norms in PA technology risks locking growers into what Law (1994, p. 111) terms 'asymmetrical relations' in which they may be 'deprived of the ability to act in certain ways'; in this case, undermining grower capacities to use PA technology in a way that suits their goals and can be adapted to their existing farming practices (see e.g., Carolan, 2016).

A further important way in which a commercial-technological mode of ordering undermines grower capacities to use PA technology is through the inscribing of *different* technical norms in the proprietary technologies produced by machinery companies (Joerges and Czarniawska, 1998). This contributes to a more complicated entangling of social and material relations in which multi-national machinery companies seek to sell their products to farmers as consumers, but where differences in technical norms inscribed by companies in their proprietary PA technologies mean that similar products from different firms are not necessarily compatible and interchangeable with one another. As the following stakeholder quotes illustrate, differences in norms governing technical design and operation raised serious doubts over how effectively rice growers could integrate PA technologies with existing farm technologies and practices.

> There are some perverse incentives and the problem is that a lot of companies want to sell more gear. They could all get together and develop [a product that's compatible] but there's not the incentive for companies to do that …. [W]hen [growers] buy one bit of gear from one manufacturer and then buy another bit of gear from another manufacturer, they're not compatible … and the software is confusing and people are using technology to do straight-line stuff. (Stakeholder 20)

> [The success of] this industry comes back to the machinery dealers and the equipment that growers have got. That's been a massive hurdle in the past and still is a massive hurdle. Everybody [is] trying to be the Apple of the precision ag world and tie everything up so it's their little bundle I suppose. And that's probably been the biggest barrier I think. Farmers are too scared to get involved because they've been burnt before, or they've heard of someone being burnt. (Stakeholder 10)

These quotes provide an apt illustration of Law's argument that while ‘a good ordering strategy is to embody a set of relations in durable materials’, the effects of those materials may change ‘when they are located in new networks of relations’ (Law, 1992, p. 387). In this case, a commercial environment where multi-national machinery companies are competing against one another to sell technology has implications for the effects of PA, making it a less durable material form for ordering the practices of growers.

From the perspective of rice growers, the competing technological platforms of different machinery companies contributed to confusion and frustration for those who had invested in PA technologies and experienced difficulties in compatibility with existing machinery. Compatibility issues contributed to frustration for growers as they posed challenges for technological flexibility and adaptability, a crucial element in enabling growers to manage effectively the varied and competing demands of a farming enterprise (see e.g., Singleton, 2010).

> One of the challenges you've got is that a lot of the systems you have, there's probably three, maybe four key systems and they're not always all compatible with each other. So, the marketing of these products tries to lock you in to their proprietary product; and that's a frustration. (MVIA, Grower 14)

> Retailers, a lot of them will tell you we'll do this and do that and like we bought another tractor that had a GPS in it last year and it won't talk to our boom spray but the system we've got will talk to our boom spray and this other one's meant to be a new flash modern technology but it won't talk to our boom spray, whereas our old one will. Just simple things like that [are frustrating]. (CIA, Grower 6)

A commercial-technological mode of ordering created frustration and cynicism for rice growers in engaging with PA technologies. However, it did not prevent implementation. This contrasts to the biophysical mode of ordering we discuss below where lack of water and a variable climate contributed to uncertainty for growers in investing in PA technologies.

5.2. Biophysical ordering

Biophysical heterogeneity is recognised as a key barrier in the industrial transformation of agriculture (Goodman et al., 1987). However, there is limited acknowledgement of the specific ways in which aspects of the biophysical environment are weaved into how farmers engage with new technology – an issue that we argue below can be addressed by applying an analytic of ordering. From our data, it was evident that biophysical phenomena such as drought and water, including the regulation of water, were crucial influences on rice production and the decisions farmers made concerning PA – what we refer to as biophysical ordering. As Law (1991, p. 173) argues, ‘naturally occurring events, objects and processes’ are an important part of the ordering of ‘the social’. On the one hand, biophysical ordering may be viewed as a mode of ordering where there is limited or no direct human activity involved (Donaldson and Wood, 2008, p. 380), such as in the influence of weather or disease on farming practice. On the other hand, it is important to acknowledge the strategic dimension of such ordering in which policies and programmes seek to impose order on non-human entities and assemble these into particular configurations (Donaldson and Wood, 2008, p. 380). In the following discussion, we highlight these two dimensions of biophysical ordering by examining: (a) the broader constraints imposed on rice growers by drought, and consequent lack of water; and (b) the ways in which regulation of water through water allocations created financial uncertainty for growers and reluctance to spend money on PA technologies.

Water availability is widely recognised as a key constraint on agricultural production in Australia (Department of Agriculture Fisheries and Forestry, 2013, p. 23). As an irrigated crop, rice production relies on water and is therefore particularly susceptible to declines in water availability, such as during periods of drought. The ‘Millennium Drought’ from 2001 to 2009 had a particularly severe effect on the rice industry with yields reduced to as little as one per cent of normal production during this time (Evans, 2007). While 2010–2012 were wetter than average years, dry conditions started to return from 2013. The long period of recovery from the Millennium Drought, as well as the recent return to drought conditions, is recognised by stakeholders as a major ongoing challenge for rice production.

> [Water is the] most limiting factor of growing rice. There's plenty of land there, plenty of skills to grow it, as in good managers, good farmers. There's market demand for the product, there's all the nutritional products [that] are out there, the varieties are out there; we just haven't got the water. (Stakeholder 14)

> Drought [is a major challenge for the industry] … because we have a high requirement for irrigation water and as such, when drought hits the region our industry, probably more than others, drops away in production quickly. There's a buffering, a seasonal buffering, by virtue of water storage from year to year but when you look at the statistics on what happened to rice production during the Millennium Drought then you realise that we're vulnerable to drought. (Stakeholder 13)

The high susceptibility of Australian rice production to seasonal variations in rainfall is an example of biophysical ordering that involves little direct human activity (Donaldson and Wood, 2008), and where the materiality of climate has a dominating influence on the social and economic relations underpinning farming. In this context, as Stakeholder 14 observes, water availability is central to all the other ‘enablers’ of a successful rice industry, including good farm management, land to grow rice, and market demand.

In times of drought, the limited overall availability of water has a significant impact on rice growers' water allocations. Drawing on Donaldson and Wood (2008), this is an example of the strategic dimension of biophysical ordering in which governments have sought to impose order on a non-human entity (in this case water) through the introduction and management of water allocations. In Australia, land ownership and water rights are separated. The creation of an upper limit on water diversions in the late 1990s led to the emergence of water markets, and in particular the creation of tradable property rights for water, which were made operational via State legislation (Bell and Quiggan, 2008). An important consequence of this change is that landholders are entitled ‘to a fixed (though variable) share of *available* water’ determined by government, and varying annually ‘in the context of changing hydrology, seasonal conditions and catchment-based water plans’ (Bell and Quiggan, 2008, p. 716, emphasis added). A closely related consequence is that the seasonal volume of water available has an impact on the price of water. According to stakeholders, seasonal variations in water availability, and thus allocation and pricing, creates considerable uncertainty for growers in all aspects of farm planning and decision-making. For example:

> At the start of the season [government allocates] us a proposed percentage for water use that we can use out of our 100%

[allocation]. At the start of this season we were only given [around] 20, 30 per cent … so our rice area is down 40 per cent … and then the price of water went up substantially. Then you've got people who have sold water off to remain viable that have to buy all their water in, and it was uneconomical for them to buy all their water back in to grow rice. (Stakeholder 8)

From the perspective of growers, uncertainty over water allocations and prices has an impact on their capacities to engage with PA technologies, making it difficult to justify the cost of new equipment.

To spend money on the farm you have to have confidence in the future and we have developed the farm a lot but right now it's hard to have confidence in the future because it all hinges on water allocations. And like I couldn't even tell you, right now, well nobody knows what our next year's allocation will be and so it's a big call to spend a lot of money on [new technology]. (MVIA, Grower 17)

I probably invest as much away from farming as I do in my farm and that's because I really struggle with our variable climate here and our variable water allocation. (MVIA, Grower 16)

As Law (1994, p. 111) argues, modes of ordering 'may generate and embody a characteristic set of problems'. In the case of biophysical ordering in the rice industry, water allocations generate a set of problems for growers in determining how to best invest their limited resources. For these growers, water availability is closely intertwined with their financial bottom line. Ongoing limitations on this availability as a consequence of drought contribute to uncertainty in their planning and reluctance to make large capital outlays, such as for PA technologies. In this sense, biophysical ordering is a highly durable mode of ordering in terms of its ongoing influence over all aspects of grower decision-making.

The two modes of ordering discussed thus far each have the effect of constraining the conditions of possibility for rice growers to engage with PA technologies. However, these forms of ordering do not necessarily 'add up' (Law and Mol, 1995) to provide a complete explanation of how farmers engage with PA. As Moser (2005, p. 689) argues, 'there is an important form of openness in the material practice of ordering', and far from being stable and settled, multiple processes of ordering can give rise to 'already practised, or yet unknown and unimagined' alternative possibilities. In the final section of this paper, we turn to the ways in which growers in our study sought to create alternative possibilities for engaging with PA through negotiating, working with, and working around, the two modes of ordering discussed above. We conceptualise this work as *tinkering* and argue that while it is partly a consequence of the constraints imposed by the commercial-technological and biophysical modes of ordering, tinkering also comprises an important form of ordering in its own right.

5.3. Negotiating technology on-farm: tinkering as a mode of ordering

Farmers' tacit knowledge, and the production of that knowledge within complex social and cultural processes, is recognised by rural sociologists and geographers as crucial in understanding how farmers engage with new technologies, practices and programmes (e.g., Morris, 2006; Riley, 2008; Tsouvalis et al., 2000). Less clear in this literature are the actual strategies that farmers use to negotiate, work around, and adapt new practices so that they are able to be worked into an alignment with existing knowledge-practices and farming goals. We argue that the notion of tinkering provides a way of conceptualising this important work performed by farmers by drawing attention to the 'constantly unfolding and only partially routinized practices for holding together that which does not necessarily hold together' (Law, 2010, p. 69). Such practices involve careful experimentation, adaptation and embodied learning through which farmers seek to skillfully incorporate multiple non-farm cares – such as food security, environmental management, and, in the case of this paper, PA – 'into their principal concern for caring for the farm as an economic [and social] unit' (Krzywoszynska, 2016, p. 305). Tinkering is therefore closely intertwined with 'good care' for one's farm. At the same time, the intertwining of tinkering and good care is of particular relevance to technology adoption. As Mol et al. (2010, p. 15) argue, technology implementation depends crucially on care work, 'on people willing to adapt their tools to a specific situation while adapting the situation to the tools, on and on, endlessly tinkering'. In what follows, we discuss two different forms of tinkering through which rice growers in our study sought to work with, and around, the constraints imposed by the modes of ordering outlined previously, and to weave elements of PA into their existing farming care practices.

The first form of tinkering used by growers was adaptation of new technology to work with existing machinery. Adaptation is recognised as an important dimension of the adoption process. As R. Wilkinson (2011b, p. 45) argues, 'without adaptation, adoption is likely to be slow and, in many cases inappropriate'. This is particularly relevant to complex technologies, such as PA, which may not be straightforward for farmers to integrate into existing farming systems and practices. As a form of tinkering, adaptation is a material process involving growers adjusting PA technologies to fit with existing equipment, knowledge and priorities; what Mol et al. (2010, p. 15) refer to as adapting 'tools to a specific situation'. At the same time, adaptation enables growers to address the asymmetrical relations enacted through the commercial-technological mode of ordering[1]. Thus, for the growers in our study, adapting technology was crucial in working around the constraints imposed by different technical norms inscribed in the proprietary technologies of machinery manufacturers. Rather than putting up with the frustration of using different and incompatible platforms, or pursuing the costly option of purchasing equipment from one brand only, adaptation therefore provided a valuable alternative for growers.

… it's very hard because we've got implements all over the place. So what do we do? Do we sell them all and upgrade to new, there's probably I don't know, $500,000 right there, if not more. And currently with the current climate in farming, like commodity prices and the water, it's just not justified [to upgrade to new machinery with GPS]. So we try and adapt to the main machinery that we use, that's all I've done, is adapt it to the main machinery and we put up with the other stuff. (MVIA, Grower 25)

… it doesn't really matter whether it's IT type technology, precision ag stuff, or whether it's the hard physical stuff, shift the dirt, move the water stuff, the same rules apply. You fiddle with it for a while, you bend it to suit yourself. (MVIA, Grower 11).

From the perspective of stakeholders too, adaptation was

[1] Carolan's (2016) recent work on farm hacking networks, which promote 'technology that is collectively built and freely shared' (p.2), provides an excellent example of how farmers tinker with technology in ways that address the asymmetrical relations imposed by legal and digital 'locks' on machinery manufacturers' proprietary technologies.

essential in making PA cost-effective and workable. For example:

> The important thing I think for our extension program is to increasingly make people aware of cost effective options, to say “look, you don't necessarily have to buy all new bits of green equipment, or all new bits of red equipment, for this system to work”. But those in the know tell us, here are the shortcuts you can take and the fixes you can make to your own system with your own bits of gear. (Stakeholder 20)

> You can't really just go and prescribe, this is what you're going to do, because every situation is so different …. Local knowledge and adaptation, and paddock adaptation is critical to be successful. (Stakeholder 5)

Nevertheless, while adaptation was seen as a necessary part of making new technology workable with existing farming practices and priorities, it was also recognised as a risky and potentially time-consuming task, and not necessarily applicable to all growers.

> I've got the blokes that have adapted GPS thing to ancient tractors. Some horror stories. But generally if they persist they'll get it to work. But again, the amount of time that they've spent trying to adapt it to the old gear is, whether it was worth it. (MIA, Grower 2)

> It's sort of a specialised area. Your local re-seller probably understands the new tractor, new GPS stuff, but doesn't understand old tractors and old GPS stuff. So there's a bit of that goes on. It's a bit of a mis-match of everything. And then you've got the sprayer rig talking to your Trimble GPS, then you've got your spreader talking to it, and they've got their own synergies and problems as well …. All my stuff's older machines and new stuff. You've just got to work your way through it. (MIA, Grower 4)

In this sense, the conditions of possibility for growers to adapt technology ‘are material and practical, have to be arranged and ordered, take effort and work, *and* are precarious and fragile’ (Moser, 2005, pp. 689, emphasis in original).

The second form of tinkering used by some growers was the use of other people's machinery already equipped with PA technology – such as headers with yield mapping capabilities; airseeders that use prescription maps and variable rate technology; and tractors equipped with auto-steer capability. In contrast to the adaptation of ‘tools to a specific situation’ discussed above, the use of machinery owned by other people involves ‘adapting the situation to the tools’ (Mol et al., 2010, p. 15); in this case growers adapting their farming practices so that PA technology can be integrated in a cost-effective way. For the growers in our study, the use of machinery owned by other people – such as neighbours and local farming contractors[2] – was an explicit cost-saving measure that enabled them to *work with* the financial constraints imposed by the biophysical mode of ordering and *avoid* the new equipment costs associated with the commercial-technological mode of ordering.

> Looking at different bits of equipment that are available in the market now [this] actually gives us a solution to something that was a lot harder to do, the time saving factor of updating equipment, going to larger pieces of gear and what not …. As much as I'd love to have a lot of that stuff it's not financially practical for me to adopt a lot of it. We find that in a lot of regards there's always a contractor or there's someone that's going to hire a bit of gear or there's a neighbour that's got it that you can actually get your hands on it to do the job. (MIA, Grower 18)

> [I bring] in contractors who've got the technology … rather than buy the technology. So that works. If it was blue sky, I would get someone put it into a commercial model and then sell it to me, then they can promote it to me. But all the costs have got to be figured in. (MIA, Grower 14)

> We try and minimise our equipment and we use contractors …. Contractors are reliable … we're not keen on buying equipment if we can do it that way. (MVIA, Grower 18)

Compared to adaptation of new technology, which was viewed as risky as well as time intensive, growers expressed few concerns about the use of other people's machinery. Indeed, not having to purchase costly equipment, or adapt it to meet existing practices and priorities, was seen as a ‘win-win’ for growers in avoiding frustrations with compatibility and interchangeability, and enabling them to take advantage of the benefits of PA technology without incurring the time and ongoing capital costs. Nevertheless, as one grower observed, not all contractors (and neighbours) use PA technology, and this can have a significant influence on whether or not this is used as a form of tinkering for growers.

> Well perhaps another reason why I haven't gotten into some of the technologies, because there are things like yield mapping and all of those sorts of things, well with contractors if they don't use it then it's pretty hard … so it all depends on your contractors …. I know how I could use it but it's just I haven't pushed for it with my contractor and he's not offering it. (CIA, Grower 8).

The two forms of tinkering discussed above are crucial for growers in working around or working with the constraints associated with commercial-technological and biophysical modes of ordering. In this sense, tinkering may be viewed as an important form of ordering in itself. It involves materially heterogeneous processes and implicit strategies that seek to hold together PA technology with growers' efforts to exercise ‘good care’ for their farming enterprise as an economic and social unit. At the same time, tinkering needs to be viewed in the context of other modes of ordering PA. The forms of tinkering with which growers engage are largely responses to modes of ordering that they see as constraining their capacities to implement new technology. This underlines Moser's (2005, p. 669) point that ‘*in practice*, people are not caught in any one mode of ordering’, but ‘rather slip and move between multiple modes of ordering’. Thus, tinkering co-exists with biophysical and commercial-technological modes of ordering, but at the same time enacts an alternative form of ordering for growers to make PA workable on-farm. In making PA workable, tinkering is also a crucial form of ‘knowledge in action’ (Bruckmeier and Tovey, 2008, p. 321) for growers. It enables the intertwining of tacit and embodied knowledge with practical judgements over how PA can be made to work in conditions that are materially heterogeneous, changeable and often uncertain.

6. Conclusion

In using ordering as an analytical framework, this paper has highlighted first and foremost the multiple ways in which material

[2] Growers engage the paid services of contractors when they have a specific job that needs to be done by a person with a particular skill. Contracting of specific services – such as yield mapping – provides an efficient way for growers to engage with PA techniques without incurring the high capital cost of new equipment, which may not otherwise be used on a regular basis, or may not be justified given the scale of the farming operation.

relations are significant in shaping how farmers engage with technology. Our focus on materiality provides an important contribution to the existing literature – underpinned by a socio-cultural approach to farming knowledge – where farmer engagement with new technologies, practices and programmes is viewed primarily as a consequence of social and cultural relations (e.g., Morris, 2006; Riley, 2008; Tsouvalis et al., 2000; Warren et al., 2016). Through identification of two key modes of ordering PA in the Australian rice industry – commercial-technological and biophysical – we have argued that the materiality of climatic variation and differences in technological platforms play a constitutive role in the conditions of possibility for growers to 'know' and engage with PA technology. At the same time, as part of heterogeneous modes of ordering, these material forms are interwoven with 'social' relations such as through the inscribing of different technical norms into the proprietary technologies of multi-national machinery manufacturers and efforts by governments to regulate flows of available water to agricultural production.

Identification of these two modes of ordering demonstrates that the predominant emphasis by rural studies scholars on knowledge forms or knowledge-cultures needs to be widened to take into account the more-than-cultural influences on farmer engagement with technology, and how these enable or constrain what farmers come to 'know' and do with technology. This is consistent with Carolan's (2017, p. 149) call for greater scholarly emphasis on 'the constitutive role that different entities play in constraining, enabling, and enacting ways of becoming'. Similarly, rather than investigating the socio-cultural characteristics of farming knowledge as a starting point in explaining its relationship to other knowledge-cultures, our analysis points to the need for farming knowledge to be studied as an effect of multiple modes of ordering. This enables deeper engagement with what Bruckmeier and Tovey (2008, p. 321) term 'knowledge in action' – the ways in which knowledge, social and material products are co-produced.

In addition to contributing to the literature on the relationship between farming knowledge and other knowledge-cultures, the paper also builds on and extends research utilising an ordering analytical approach in two main ways. First, whereas the literature to date has focused on dominant *or* alternative modes of ordering (Law, 1994; Moser, 2005; K. Wilkinson, 2011a), our analysis has considered in more detail how alternative and dominant ordering practices exist side-by-side and relate to one another. In doing so, we show that *tinkering* (Law, 2010; Mol et al., 2010) performed by growers constitutes an important alternative form of ordering. Previously applied in the context of medium to large organisations (Knox et al., 2008; Law, 1994; K. Wilkinson, 2011a), our attention to smaller-scale enterprises – in this case, farms – enables greater scrutiny of the alternative ordering practices that provide a way for growers to work with and work around the modes of ordering that impose constraints on their capacities to engage with PA.

Second, our data suggests that farmers' tacit knowledge is a crucial element in enacting alternative modes of ordering – in this case tinkering. From an ordering perspective, knowledge is treated 'as product or an effect of a network of heterogeneous materials' (Law, 1992, p. 381). This was evident in the commercial-technological and biophysical modes of ordering, which imposed limits on how farmers could come to 'know' and engage with PA technologies. However, tinkering involves a different mode of ordering in which the embodied skills and practical judgement of farmers – their 'craftwork' – becomes much more significant (Higgins et al., 2016; Singleton and Law, 2013). As we have shown, such skills and judgement – demonstrated through strategies such as adaptation of technology and the use of contractors' and neighbours' equipment with PA technology already installed – were crucial for growers in negotiating and working around the constraints enacted by the commercial-technological and biophysical modes of ordering. Therefore, while tinkering is important in enacting 'alternative breathing spaces' (Singleton and Law, 2013, p. 272) for growers, it also constitutes a powerful form of ordering that is flexible, adaptable, and enables technology to be locally workable. In this sense, tinkering needs to be a more central focus of analytical attention for scholars seeking to make sense of farm-level technology adoption.

In concluding, we argue that a relational approach to knowledge should remain a key focus for rural studies scholars researching farmer engagement with and adoption of technology. However, in doing so, the more-than-cultural dimensions of knowledge need to be recognised. Greater emphasis should be placed on 'knowledge in action' – the relationality of materials and the multiple modes of ordering through which materials intertwine with, shape, and are shaped by, farming knowledge and practices. The analytical approach of ordering applied in this paper demonstrates that the study of knowledge as a *co-production* of social and material products (Jasanoff, 2004) has significant implications for how technology adoption in agriculture is conceptualised. In particular, we have shown that an emphasis on ordering draws attention to the heterogeneous constraints that influence how farmers come to 'know' and implement technology, and the subtle yet powerful ways in which they work with and work around technology to make it adoptable on-farm.

Acknowledgements

We would like to thank the rice industry stakeholders and growers who participated in the research for this paper. We would also like to thank the three anonymous reviewers who provided helpful comments on an earlier version of the paper.

Funding

The research reported in this paper was supported by the Australian Rural Industries Research and Development Corporation [Grant number: PRJ-009181].

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