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Dynamics and distribution of public and private research and extension roles for technological innovation and diffusion: Case studies of the implementation and adaptation of precision farming technologies

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ABSTRACT

Precision farming technologies represent an innovation challenge in terms of their diffusion into farming practice, and create a new dynamic for research and extension roles. The purpose of this paper is to examine the interaction and distribution of research and extension roles of public, private, and agricultural industry organizations in precision farming innovation systems. We connect findings to the broader debates on role divisions of public and private research and extension in innovation systems. Two case studies were examined: precision dairy farming in Australia, and the use of automatic milking systems in north-western Europe. A timeline analysis method, underpinned by a functions of innovation systems framework, was used to examine activities of actors and organizations in the case studies. Three main findings were: 1) Complex agricultural innovations require a collaborative approach for successful innovation and diffusion. The need for, and type of, collaboration differs across scales from farm-level (individual learning) to a national and global level with issues of skill training and service provider capability. Additionally, a threshold scale is required before the commercial sector can operate effectively. 2) The presence, and limitations, of private (commercial) interests and their position as a key knowledge base in precision farming heightens the need for public research and extension organizations to promote collaborative innovation programs with technology companies. There is a key public or industry good role in providing ‘back-office’ activities to support and complement private ‘front office’ activities. 3) Public and private research and extension organizations can work together, however there are areas where it makes more sense for one party or the other to lead. For precision farming systems, the roles for public organizations involve leadership on data integration (on-farm and off-farm), integration of technology (via standards), testing equipment performance, and development of training programs including support of initiatives such as farmer clubs. The principle theoretical implication is that public, private and industry roles in research and extension should not be viewed as dichotomous (e.g. pre-competitive/competitive), but as highly fluid in terms of the moments they are needed, and the scale at which they are needed, within the technological innovation system.

1. Introduction

Agricultural systems globally are undergoing a ‘precision farming’ revolution through use of global positioning systems and the development of sensors to automate farm tasks and measure crop and animal performance (Busse et al., 2015; Jago et al., 2013; Kutter et al., 2011; Tey and Brindal, 2012). This paper focusses on dairy farming, where there is increased availability of technologies such as electronic animal identification, automation, and data collection sensors (Bewley, 2010; Berckmans, 2008). ‘Precision dairy farming’, has been observed to have economic, environmental and animal health benefits (Jensen et al., 2012; Schlageter-Tello

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et al., 2015). However, there have been lower than expected rates of adoption (Borchers and Bewley, 2015; Edwards et al., 2015) in part due to the complexity and potential unintended impacts associated with its use (Schewe and Stuart, 2014; Kutter et al., 2011).

The complexity of precision farming is, in part, due to a required change in mode of working for farmers, transitioning from experiential decision-making to data-driven processes (Eastwood and Kenny, 2009; Nuthall, 2012), and this causes uncertainty around the potential costs and benefits of the technology (Kutter et al., 2011). Often, there is strong link between uncertainty of technology users (farmers) in their relationship with suppliers (Meijer et al., 2007). Precision farming technologies are primarily developed and supplied by private companies who often lack the farm systems expertise or knowledge networks to adequately support on-farm use and adaptation (Eastwood et al., 2016). There is thus subsequent uncertainty on how to implement the technology on-farm (Hay and Pearce, 2014b) as well as off-farm, for example data transfer between on-farm and industry-level databases (Kamphuis et al., 2015). As a consequence, precision farming technologies require support structures to facilitate learning and reduction of uncertainty in the implementation and adaptation process (Bewley and Russell, 2010; Hoes et al., 2012).

Continuous learning and adaptation of new technologies such as in precision farming therefore requires several actors beyond farmers, reflecting the features of 'technological innovation systems' (TIS). TIS incorporate the actors and rules influencing the speed and direction of change in a specific technological area (Hekkert et al., 2007). Successful technological innovation and diffusion depends upon factors such as technology development, but also on complementary social innovation in the form of institutional change, supply chain reorganization, market development and creating societal acceptance (Klerkx et al., 2010). The TIS approach recognizes that technology development and resultant diffusion and adoption of technologies, is beyond the influence of individual suppliers (e.g. precision dairy equipment manufacturers) or users (e.g. farmers) of a technology. The dynamic roles of public and private actors involving interaction and knowledge flow between networks are a feature of TIS (Busse et al., 2015; Carlsson and Stankiewicz, 1991; Hekkert et al., 2007).

The TIS approach emphasizes the interplay of all relevant actors (Oreszczyn et al., 2010; Klerkx et al., 2012). In precision farming systems, actors such as researchers and technology developers, and intermediaries such as extension (including public and private farm advisors), have been identified as performing roles including reducing technology implementation uncertainty and overcoming barriers to adoption. Kutter et al. (2011) highlighted the potential for co-operation in such TIS, with roles for private contractors, and development of centralized data storage by public or collective (industry) actors. Further, in a study of German animal monitoring innovation systems, farmers played an important co-development role together with researchers and advisors from technology development to technology diffusion (Busse et al., 2015). Potentially influential but underperforming public advisory services were identified in a German precision farming study (Busse et al., 2014), with knowledge gaps between science and practice, and insufficient communication between actors as barriers to precision farming innovation. Variation in the diffusion, and thus adoption and successful use of precision farming technologies has been partly attributed to insufficient support structures (Douthwaite et al., 2001; Oreszczyn et al., 2010; Eastwood et al., 2012; Garb and Friedlander, 2014; Ingram, 2015). In some cases, public research and extension has not considered precision farming diffusion an investment priority (Jago et al., 2013). Poor collaboration between these actors is suggested to limit the realization of potential benefits or advantages (Jago et al., 2013).

The increasing use of precision farming technology is thus creating a new dynamic for public research and extension (R&E) institutions (Kutter et al., 2011; Poppe et al., 2013). Recent studies have recommended a shift in public R&E engagement in precision farming innovation toward a greater understanding of farmer adoption (Hansen, 2015; Schewe and Stuart, 2014) including roles associated with the definition of data standards and support to innovation structures (Busse et al., 2014; Jago et al., 2013; Kutter et al., 2011). However, these studies have not examined the role of public R&E in relationship to, and interaction with, private R&E in the support of broader diffusion of precision technologies. Questions surround the ability and responsibility of private technology companies to provide ongoing farming systems support of their own products, where the engagement and investment by public organizations is justified, and how a collaborative approach to precision farming innovation might be organized. Such issues of appropriate task division are also topical in the wider context of current pluralistic and privatized research and extension systems (Fuglie and Toole, 2014; Klerkx et al., 2006; Labarthe and Laurent, 2013; Prager et al., 2016). The aim of this paper is therefore to examine R&E roles of public and private organizations in precision farming innovation systems, and to identify potential collaboration to enhance innovation system functions. In the next section, we provide a conceptual framework, in which we elaborate uncertainties and functions in TIS and review literature regarding roles of different research and extension providers.

2. Conceptual framework

2.1. Roles of public, private and industry good research and extension in agricultural technology development and diffusion

Adoption of technology by farmers has been described as a process of diffusion (Rogers, 1995) influenced by several adoption variables such as education, asset position, risk taking attitude (see also Pannell et al. (2006) – for an extensive overview), and what has more broadly been called 'absorptive capacity' for new technologies (Micheels and Nolan, 2016). However, it has been argued that sometimes introduced technologies are not sufficiently adapted to the context and logic of those who are supposed to adopt them (Rogers, 1995; Leeuwis and van den Ban, 2003). The decision not to adopt is thus rational if the technology is not compatible with a farming system and farmer aspirations. Further, the relative advantage a technology provides over incumbent practice or technology impacts adoption and risk in terms of return on investment or the cost of failure (Marra et al., 2003; Pannell et al., 2006; Hay and Pearce, 2014a) and developed knowledge and processes around a current practice, can create a form of lock-in where new innovation has to provide advantage above a threshold before sustained change occurs (Dodgson et al., 2011). To enhance adoption success, the conditions and preferences of different adopter groups must be considered (Jansen et al., 2010; Leeuwis and van den Ban, 2003). Hence, studies have highlighted adaptation and learning processes as central to adoption, and learning support as a role for R&E actors (Douthwaite et al., 2001; Millar and Connell, 2010; Schut et al., 2015).

Private sector R&E organizations have roles related to intellectual property protected activities (Pardey et al., 2010) and applied research that can lead to commercial products and activities, while public sector roles are usually directed to 'socially worthwhile' issues such as environmental impacts of agriculture and basic 'blue sky' research (Huffman and Just, 1999). With respect to extension, it is has been identified the private sector focus on private goods (e.g. fertilizer application advice) and others on public goods (e.g. environmental management) (Kidd et al., 2000; Klerkx et al., 2006;