Challenges to effective interaction in the New Zealand agricultural research and extension system: an innovation systems analysis

James A Turner[1], Kelly Rijswijk[1], Tracy Williams[2], Tim Barnard[3] and Laurens Klerkx[4]

[1] AgResearch Limited, Private Bag 3123, Hamilton 3214, NZ
[2] The New Zealand Institute for Plant & Food Research Ltd, Private Bag 4704, Christchurch 8140, NZ
[3] Scion, Private Bag 3020, Rotorua 3046, NZ
[4] Knowledge, Technology and Innovation Group, Wageningen University, PO Box 8130, 6700 EW Wageningen, The Netherlands
Email: james.turner@agresearch.co.nz

Abstract. This study used semi-structured interviews to evaluate the perceived effectiveness of interactions among those mandated to develop and diffuse knowledge that meets the identified needs of farmers/growers in the New Zealand primary sector, as well as the users of knowledge, practices and technologies. We used the systemic innovation policy framework, which integrates the structural and functional streams of innovation system enquiry. This enabled analysis of the effectiveness of the functions that support technology co-development, along with the presence and quality of the structural components that are needed for these functions to be effective. Key lessons are the need for: (i) incentivising individuals that are able to effectively act as translators between science and farmers/growers, (ii) strengthening of interactions between research organisations and industry good bodies in knowledge development, setting strategic direction for innovation efforts and exchanging knowledge, and (iii) institutional support for greater collaboration among government, industry, research and users.

Keywords: agricultural innovation system, technology co-development, innovation, interviews, innovation processes, New Zealand.

Introduction

Modest uptake of new technologies and practices within the New Zealand primary sector has been estimated to have important impacts on the New Zealand economy: NZ$2.5 billion per annum lower dairy exports and NZ$0.5 billion per annum lower sheep meat exports because the lower 75% of pastoral farms do not use the practices adopted by the top 25% (MPI 2011). An example of poor uptake of potentially beneficial technologies includes precision agriculture in arable farming, with only a small number of leading farmers and contractors using Real Time Kinematic systems (Pyke 2011). Another example is the low uptake of Integrated Pest Management (IPM) in vegetable brassica crops throughout the 1980s despite evidence of pesticides beginning to fail and demonstration of the economic benefits of IPM (Beck et al. 1992; Cameron 2007).

Until the 1980s New Zealand's agricultural extension services were delivered as a public good through the then Ministry of Agriculture and Fisheries. From the mid-1980s agricultural extension was commercialised and then privatised (Botha et al. 2006; Morriss et al. 2006). Subsequent to these changes in agricultural extension, between 1999 and 2001 there was also significant legislative reform of Producer Board powers and industry structures (Morriss et al. 2006). This contributed to the fragmentation of activities supporting uptake of technologies and wider innovation, among industry, industry good bodies, rural advisors, local government, the Crown Research Institutes (CRIs), and research funding mechanisms such as the Sustainable Farming Fund (SFF) (Morriss et al. 2006; Botha et al. 2010; McEntee 2010).

The Ministry for Primary Industries (MPI) (2012) recently undertook a survey of providers of services to support technology uptake in the New Zealand primary sector. This highlighted the fragmented nature of support for technology uptake. The survey also identified insufficient numbers of people devoted to supporting technology uptake as another challenge to increasing adoption rates across the New Zealand primary sector. Recommendations from the survey were for: (i) improved interaction among those involved in supporting technology uptake, and (ii) more skilled people in extension services. Hartwich and Negro (2010) used network analysis to study the patterns of formal and informal collaboration in research and development in the New Zealand dairy industry in 2007. They concluded that the dairy innovation system is dependent on the capacity of a few public and industry organisations. In reviewing schemes for funding innovation activities, the authors suggested that funding schemes did not explicitly foster collaboration and mechanisms to support informal collaboration were underdeveloped.

Arguments for improving the interaction among those developing, delivering and using technology also come from participatory and systemic approaches to research uptake and innovation (e.g. Röling 2009). These approaches emphasise the importance of research and

technology development processes that explicitly deliver desired outcomes for participants. Central to achieving this is the complementary role of end users in determining the objectives of development, as well as utilising their skills and knowledge in the design and undertaking of the research and translating research results into technologies and practices so that technology and innovation is 'co-produced' (Forester 1999; Klerkx and Nettle 2013). McEntee (2010) interviewed crop sector participants and users of participatory research in New Zealand. Her findings suggested that interaction in research that purports to be participatory remains less than ideal. This was due to traditional approaches to agricultural extension remaining integral to many attempts at participatory approaches, and science and industry objectives often being poorly aligned. Attempting to address the latter, Morriss et al. (2006) demonstrated the potential benefits of a policy systems analysis and mediation (PSAM) approach to facilitate shared understanding among stakeholders in the on-farm sector of the New Zealand dairy industry. The PSAM process includes establishing stakeholder perspectives, developing propositions for action, establishing areas of alignment and misalignment among stakeholders, clarifying opportunities for change, and negotiation among stakeholders (Morriss et al. 2006).

Beyond including end users of technology (such as farmers/growers), often several actors along the value chain also need to be involved to provide their input to technology development and create an enabling environment for technology to become embedded (Devaux et al. 2009; Hounkonnou et al. 2012). This type of thinking on the benefits of innovation that is co-produced has evolved and has been captured in several systems approaches to innovation, amongst which the Agricultural Innovation Systems (AIS) approach is the most comprehensive to date (Röling 2009; Klerkx et al. 2012). The AIS is defined as 'a network of organisations, enterprises, and individuals focused on bringing new products, new processes, and new forms of organisation into economic use, together with the institutions and policies that affect the way different agents interact, share, access, exchange and use knowledge' (World Bank 2006, pp. vi–vii).

The purpose of this current study was to evaluate the status of activities in the New Zealand AIS that support technology co-development in the primary sector (what could be called the Agricultural Knowledge and Information System, consisting of organisations and individuals contributing to primary sector research and extension), using an innovation systems lens, with its focus on effective interactions and conducive institutions. Our particular focus was on the presence and effectiveness of interactions among those formally mandated to develop and diffuse knowledge, practices and technologies that meet the identified needs of farmers/ growers in the New Zealand primary sector, as well as the users of knowledge, practices and technologies.

Methodology

While there are several tools available to analyse the AIS (Klerkx et al. 2012), many only look at certain elements (e.g. policies, patent analysis, social networks). A comprehensive framework for analysing AIS is the systemic innovation policy framework of Wiezcorek and Hekkert (2012). This framework integrates two streams of innovation system enquiry – structural and functional – to enable analysis of the effectiveness of the important functions (or processes) that support innovation, along with the presence and quality of the structural components that are needed for these functions to be effective. The structural view of the innovation system (Nelson 1993) focuses on the composition of the AIS: the presence of actors (such as research, firms, government, and involved users), interactions among the actors, the rules of the game (institutions) that influence interactions of actors and supporting infrastructure (e.g. funding organisations, patent offices). To the structures identified by Wiezcorek and Hekkert (2012) we have added market structure, which refers to the position and relations among participants in the market (Van Mierlo et al. 2010). The functional view (Hekkert et al. 2007) focuses on the processes that contribute to successful innovation in the AIS, and the structural components needed for the innovation system to be able to perform. Hekkert et al. (2007) describe seven functions that need to be present in innovation systems for successful innovation to occur: (i) entrepreneurial activities, (ii) knowledge development, (iii) knowledge diffusion, (iv) guidance of the search, (v) market formation, (vi) resource mobilisation (e.g. finance) and (vii) creating legitimacy for change. The functioning of each of these processes is dependent on the four structural components of the AIS: actors, institutions, interactions, infrastructure (Wieczorek and Hekkert 2012) and market structure (Van Mierlo et al. 2010). For example, knowledge development involves research organisations, such as Crown Research Institutes (actors), operating under various acts of parliament (institutions) that guide how these organisations develop knowledge, interact with other actors (such as funding agencies and industry) to access research grants, develop industry strategic documents, and

apply existing technologies (embedded in physical infrastructure) to address pressing sector problems.

For this paper we focus on the actors and their interactions involved in three of the seven functions, which have been traditionally associated with the research and extension system: guidance of the search, knowledge development and knowledge diffusion (Hekkert et al. 2007). In keeping with the World Bank (2006) definition of the AIS throughout we refer to 'knowledge diffusion' as 'knowledge exchange'. This latter term also better reflects the two-way nature of sharing and co-construction of knowledge. We have focused on these three functions as they are most concerned with knowledge produced by the formal system of research and extension and its exchange with end users.

Knowledge development and learning are at the heart of any innovation process (Nieuwenhuis 2002; Ingram 2008). A study of technological learning by New Zealand dairy farmers highlighted the importance of three factors on the extent to which famers engaged in technological learning: farm system characteristics, individual farmer characteristics and circumstances, and characteristics of the innovation system in which farmers operate (Morriss et al. 2006). The knowledge development function encompasses 'learning by searching' and 'learning by doing'. Learning by searching is the systematic and organised search for new knowledge to acquire 'know-why', such as research, and includes 'learning by studying' (Kamp et al. 2004). Learning by doing is the trial-and-error practical experience gained when producing a technology and it generates 'know-how'. Learning by doing involves developing 'rules of thumb' and therefore generates mainly tacit knowledge (Kamp et al. 2004).

Interactions that enable effective knowledge exchange, and more broadly co-construction, are an essential function of innovation (Nieuwenhuis 2002; Ingram 2008). McEntee (2010) provides an example of this for the case of the Wheat Calculator project, where uptake of the technology has declined, though there is evidence of learning through interactive activities between growers and researchers who use the Wheat Calculator, leading to changes in nutrient management practices by wheat growers. In these circumstances, interaction can be regarded as a precondition to 'learning by interacting' and 'learning by using' (Hekkert et al. 2007). 'Learning by interacting' is the co-construction of knowledge between actors engaged in an innovation process, especially between users and producers of technology through persistent face-to-face interaction (Lundvall 1992; Kamp et al. 2004; Ingram 2008). 'Learning by using' is know-how acquired, particularly by users, in the use of a technology. An important condition for this type of learning is the interaction between producers and users of the technology (Kamp et al. 2004).

Guidance of the search refers to activities that positively affect the visibility and clarity of specific wants among technology users (Hekkert et al. 2007). McEntee (2010) found evidence of a misalignment of scientist and industry collaborator objectives in SFF projects, with industry wanting knowledge that can be applied by farmers/growers while for scientists the objective was a publishable output. Morriss et al. (2006) found misalignment between objectives identified by scientists leading the research, with the intention of gathering publishable evidence, and industry objectives, which negatively influenced engagement of farmers/growers in learning about new technologies for improving productivity on New Zealand dairy farms.

The presence (absence) of and relationships among the five structural components of the AIS enable us to understand why the three studied functions are absent or weak (Klein Woolthuis et al. 2005; Wieczorek and Hekkert 2012); which have been referred to as innovation system failure or problems. For example, hard institutions (regulations) or soft institutions (established practices) incentivising research organisations to undertake activities that support uptake of knowledge, practices or technologies may be absent or weak (e.g. Hartwich and Negro 2010; McEntee 2010). Alternatively, the interaction between research organisations and industry may be weak due to differences in organisational objectives (e.g. Morriss et al. 2006). The absence of these institutions and interactions in the AIS could contribute to the knowledge exchange function being weak.

The systemic innovation policy framework (Wieczorek and Hekkert 2012) was used to develop a framework for semi-structured interviews with 28 individuals from government (3), industry, such as processors (2), industry good bodies (10), research (8) and technology users, such as farmers/growers (5) in the New Zealand pastoral, forestry, cropping and horticultural sectors. These individuals are from organisations with key roles in the New Zealand primary sector in undertaking one or more of the seven functions for effective innovation identified by Hekkert et al. (2007). Twenty of the interviewees were individuals who had indicated an interest in the larger research programme, 'Co-innovation and co-learning for increased impact' (MBIE 2012), of which this study is a part. The additional eight individuals were selected using a traditional

snowball sampling technique; key informants identifying other potential interviewees (Babbie 2001). Three interviewers separately undertook the interviews, with 14 of the interviews being undertaken by two interviewers; one leading the interview with the other following up themes emerging during the interview.

The three aspects of the systemic innovation policy framework that were covered in each interview were: (i) functions, (ii) structural components that deliver each function, and (iii) the presence/absence or capability/quality of structural components. The interviews were transcribed, provided to interviewees that had requested a copy of the transcript for review and then coded in Nvivo v. 10 (QSR International 2012) by the interviewers using the systemic innovation policy framework as the coding structure. The interviewers jointly conducted thematic analysis of the coded interviews (Merriam 2009) to identify systemic challenges by exploring recurring themes across interviewee sectors and organisation types and exploring links among challenges. A follow-up workshop with interviewees provided a check on the validity of the systemic challenges identified against their own experiences (Suter 2012).

The reason for using semi-structured interviews is that they allow flexibility for both the interviewer to focus more on interesting comments and exploring these comments, and for the interviewee to talk about topics of interest, thus creating a more in-depth interview (Bruges and Smith 2010). It also allows the interviewee to generate a story or narrative that reflects the space and situation of the interviewee (e.g. Spash 2001), rather than a high-level discussion about the topics generated by the interviewer. This will ultimately create more insight into their perspectives, and corresponds with the aim of the interviews, which was to get an overview of the current status of the New Zealand AIS as it is perceived by interview participants (i.e. actors in the system). The other benefit was that the semi-structured interviews allowed the interviewer to step away from the technical language of the systemic innovation policy framework, which most of the participants are not familiar with.

Results and discussion

We now look at the effect of interactions on ways the three functions of guidance of the search, knowledge development and knowledge exchange are shaped as well as structural factors that influence these (e.g. in terms of infrastructure, institutions, relationships, capabilities) and activities in the New Zealand AIS that support technology co-development in the primary sector (i.e. mainly focused on research and extension and the end-user, farmers).

Overall interactions

All of those interviewed perceived interactions among individuals across some or all of industry, farmers/growers, research organisations, industry bodies and other organisations to be important for effective guidance of the search, and knowledge development and exchange in the New Zealand primary sectors. This was true for representatives from across all of the types of organisations interviewed, such as from an industry-research organisation partnership:

> I think from my experience, having engagement with end users, as the science is actually being undertaken is valuable, as not only does it get buy in from end users, but it also helps deal with any issues and priorities or problems that come up along the way.

and from a research organisation:

> … as a researcher…in terms of encouraging innovation and adoption, one of the most important things you can do is have those constructive conversations with decision makers …

Essential to these relationships is an understanding of each other's organisational cultures and needs. This was particularly mentioned by industry and industry bodies, who prized researchers who understood their business culture and the importance of business confidentiality, and were therefore trusted to participate in aspects of their organisation's strategic decision making. For example, an industry body representative on the types of researchers that have a good relationship with their industry said:

> I tend to think that most of these sorts of people have probably come often from industry or worked in industry at some point and they're actually really au fait with what we do, often, those type of people because they have an interest in it and they've gone out there and talked to industry and have sat down and had a beer with industry …

However, a small number of those interviewed also mentioned the challenges of developing and maintaining one-to-one interactions that enable effective guidance of the search, and knowledge development and exchange. Two stressed the importance of organisation-level support for one-to-one relationships to ensure that cross-organisational relationships are maintained, such as when individuals move on from an organisation. Another industry

participant stressed the challenge of resourcing closer and more effective interactions among organisations in their sector when referring to the diagram of interactions they had drawn:

> ... yeah we love to draw these diagrams and sort of create this positive atmosphere around innovation and everybody co-innovating, but it's hell of an expense.

Interactions for effective guidance of the search

Guidance of the search helps direct activity in knowledge development by clarifying the needs of users and focusing resources on needed research. This was recognised by several participants across industry and research organisations. Most representatives from industry and industry bodies perceived the key interactions for guidance of the search as being among industry participants along the value chain, from farmers/growers through to market. An example of the desired type of interaction was a company encouraging direct interaction between its customers and research staff to understand each other's needs and constraints:

> And so getting those customers into your test kitchens, into your R&D centres working alongside your development staff making sure that you actually understand what it is they want can shorten pipelines hugely and you get much better innovation. The same as sending these guys to the customer, send them into the market and then seeing how the product is used.

Individuals from industry bodies saw their organisations as having an important role in guiding research agendas successfully. This role was fulfilled by facilitating interactions among a large number of users, such as farmers/growers, and across other actors in the value chain. This view of industry bodies as linking industry participants is reflected in quotes from interviewees from two different industry bodies:

> [industry body's] role is that it kind of links, its got, it's like a cell with receptors on it.

> We're a hub, so we're a coordination point and that is one of the key areas that we undertake, that co-ordination.

While participants from industry bodies perceived themselves in a role of facilitating interactions to guide innovation, they, as well as industry participants, identified a vertically and horizontally fragmented market structure as a significant hindrance to effective guidance of the search. Vertical fragmentation refers to different parts of the value chain being in separate ownership. For example, few forestry companies in New Zealand own forests, harvesting, processing and export operations. Horizontal fragmentation refers to industries characterised by a large number of separate owners. Both the New Zealand forestry and red meat sectors have a large number of small processors. This challenge is captured in a quote from an industry body representative working in a fragmented sector who saw meeting the needs of all levy payers as an aspiration, while facilitation towards innovative outcomes was a more realistic goal:

> The ... industry is a de-regulated industry and therefore there are lots of business models and separate businesses that have their own goals within the industry's goals. … having all of them working in a unified way as one organism is probably impossible as well. Finding outcomes that they can all achieve in their own way is really the way to move forward.

The majority of interviewees from industry and industry bodies, as well as two research organisation participants, identified a lack of strategic leadership in their respective industries as also significantly hindering effective guidance of the search. An example is from a research organisation participant with reference to industry-research partnerships:

> Yeah, some of them do their jobs well … but many of them become barriers … and their argument is their raison d'être is to interpret and to frame up research. Actually what they do is become control agents and they don't, most of them are not strategic, most of them are quite introverted with their sector.

This lack of strategic leadership was perceived by three research organisation participants as a source of frustration in terms of being able to effectively guide knowledge development in their sector. Two of these participants had mentioned that in these circumstances they had sought out individual innovative companies to work with in the absence of industry strategic guidance. An example of this is the following quote:

> So the industry linkages, whether they're through industry entities, [my preference] is to go directly to the manager, …, the new plastics company and talk to them.

A number of interviewees from industry bodies and research organisations described characteristics of strategic leadership that they perceived were needed to support effective guidance of the search in their respective industries: the ability to take a systemic view, interact with multiple organisations, understand each of their individual circumstances, and identify their own organisation's role in achieving the wider strategy.

Only three industry participants, one of whom is from an industry-research partnership, mentioned that including research organisations improved the effectiveness of guidance of the search. For the industry-research partnership, research organisations provided input to what is technically feasible and being able to think longer term.

Interactions for effective knowledge development

All of those interviewed referred to the importance of interactions among research organisations, between research organisations and industry, and between researchers and farmers/growers for effective knowledge development. The value of the last type of interaction was emphasised by a farmer when discussing how they could benefit from a more formal interaction with scientists undertaking research of interest to them:

> ... yeah if [research organisation] and the ... company were able to sit down and say, 'Right this is what we're trying to develop, how can we make, can you see a place for this on the farm, can you see this working as a [company]?' I think that sort of more formal part would be very useful because then we can say, 'Well actually we don't see that, see some as actually being useful within our industry or in that area'.

The importance of collaboration among different research disciplines in addressing complex real world problems is well known (e.g. Holm et al. 2013). The need to enable interactions among research organisations to achieve this was identified by a few interviewees. An industry body participant commenting on weak interactions among research organisations highlighted that the nature of the problems their industry faces cuts across research boundaries:

> The interaction between CRIs is legendary – they're all at each other's throat basically for the next buck ... they don't speak to each other unless they have to, or someone puts a big stick over their head ... they're competing over the same dollar and you know, a lot of these things [problems facing the industry] are seamless.

Several participants from both industry bodies and research organisations explicitly pointed to recent reforms in the New Zealand science sector, specifically the Crown Research Institute (CRI) Taskforce Review (CRI Taskforce 2010), as leading to institutional changes that have improved interactions among research organisations and between research organisations and industry. Key recommendations from the CRI Taskforce Review were increasing funding that was managed by each CRI (core funding) to align with the needs of the sectors they work with, increasing each CRI's accountability for research that clearly delivers impact to the sectors they work with, and identifying areas of research activity that each CRI is responsible for leading (Statement of Core Purpose). An industry participant mentioned the value of the increased collaboration among research organisations and between research organisations and industry enabled by the CRI Taskforce Review:

> That process of redefining what [research organisation] is and the other CRIs' core strategic intents is, are hugely valuable and I think that to me has been a key driver of change within the organisation.

While the CRI Taskforce Review was perceived as leading to improved interactions among research organisations and industry, several of those interviewed from research organisations, industry bodies and government identified ongoing organisational barriers to increasing the interaction between research organisations and knowledge users. These barriers included ongoing competition for funding among research organisations, an historic research culture of operating in disciplinary silos, and funding mechanisms that focused on academic criteria for evaluating research proposals. A comment by a researcher captured this culture:

> ... because we live and die as scientists by what we can get. We have to be hunters and gatherers and go out there and get stuff in order to exist. ... it's a very primary behaviour by scientists because of the way science is funded and the way science has been made ...

Interactions for effective knowledge exchange

All of those interviewed mentioned interactions among a variety of actors as being important in facilitating knowledge exchange: researchers and farmers/growers, industry and farmers/growers, farmers/growers with other farmers/growers, rural advisors and farmers/growers, and research organisations and industry good bodies. While information on the effectiveness of each of these interactions was captured in the interviews, here we focus on one type of interaction that has often been explored in the literature on extension and participatory research approaches (e.g. Röling 2009; Neef and Neubert 2011), is obviously critical to technology co-development, and for which there is a range of evidence from considerable success to resounding failure; researchers and farmers/growers.

A farmer interviewed mentioned the value of directly interacting with scientists undertaking trials on his farm as a way of getting access to new knowledge as well as prompting interactions with neighbouring farmers/growers that facilitated knowledge exchange:

> Well that's basically what happens, this is where [scientist] arrived and said, 'Well look we're setting up this research would you be happy to participate?' And I said, 'Yeah I'm always keen to participate in that sort of work.' Because I can see the benefit for the [group] and myself and just the whole ... industry if we can get these innovations up and running and make them work.

Interactions among farmers/growers were also mentioned by industry and industry good body participants as a potentially effective mechanism for knowledge exchange. The majority of those interviewed from both research organisations and industry highlighted a key challenge to the effectiveness of the interaction between researchers and farmers/growers was the need for individuals (either in research or industry) with the ability to operate as translators between actors in knowledge exchange. An example is this quote from an industry participant when asked about the role his company played in delivering science findings to their suppliers:

> But in many cases it's actually more valuable if someone else does that for us. So [scientist], for example, is fantastic in that space. He talks farmer language, he's, and he has a good science background and knows the data and understands these things, and understands farmer systems, so he's a great translator.

Those interviewed identified characteristics of effective translators: independence from organisations that may be perceived as having a vested interest, respected by farmers/growers, talk farmers'/growers' language, have combined farm system and science knowledge, ability to appreciate other's world views, and an understanding of innovation as the combining of technology, policy and practice. A number of these characteristics were identified by Ingram (2008) as being associated with agronomist-farmer interactions that are more effective at potentially facilitating farmers' shift to more sustainable best management practices in England; they include the importance of trust, credibility, empathy and consultation.

Some of those interviewed from industry identified reasons why there is a lack of individuals with translation skills. Contributing factors included the challenge of attracting people to agricultural degrees; good agricultural students tend to be picked up by banks; translator-type roles, such as in extension, are commonly seen as stepping stones to other roles, resulting in a high turnover; and a lack of time to develop trust between translators and farmers/growers.

One institutional barrier to effective interaction between farmers/growers and researchers mentioned by participants from government, farming and research organisations was the culture of research organisations continually seeking funding for research:

> ... so often a focus is on generating new knowledge but also attracting funding, which means at times that may get over-emphasised ... funding may dry up before that innovation process is finished. And so there's a challenge, if you like, for all of us about how do you continue that innovation process when you're, when the CRI drip funding may have stopped?

McEntee (2010, p. 5) found a similar effect of the competitive funding environment in New Zealand, reporting that: 'Scientists also frequently claim that the competitive funding model has limited their ability to engage with stakeholders, and that 'extension' is difficult to budget and account for in a system they perceive as biased towards reports and scientific publications'.

In this paper we have focused on just one aspect of a wider conceptual framework that is guiding our analysis – the presence and effectiveness of interactions among those formally mandated to develop, exchange and use knowledge that meets the identified needs of farmers/growers in the New Zealand primary sector. In this regard, all interviewees perceived one-to-one interactions across industry, farmers/growers, research organisations, industry bodies and other organisations to be important for effective guidance of the search, and knowledge development and exchange in the New Zealand primary sectors. However, in the current AIS there are key systemic challenges to the effective functioning of activities that support technology co-development (Table 1). These systemic challenges (barriers, failures or imperfections) occur when innovation systems do not work as systems, hindering learning and innovation (Klerkx et al. 2012). Different categories of systemic challenges exist (Klein Woolthuis et al. 2005; van Mierlo et al. 2010; Wiezcorek and Hekkert 2012) (Table 1).

Table 1. Systemic challenges to effective interaction based on a structural-functional analysis of the New Zealand agricultural research and extension system

System function	Structural element	Type of systemic problem
Guidance of the search	Actors	Lack of researchers who understand business culture
		Lack of strategic leadership capability in some industries
	Institutions	Absence of organisation-level support for individual interactions in some cases
	Interactions	Weak research-industry interactions
	Infrastructure	Low provision of resources for supporting interactions for guidance of the search
	Market structure	Vertical and horizontal fragmentation in some industries hampers the formation of strategic direction
Knowledge development	Actors	
	Institutions	Competitive funding focused on academic criteria of success
	Interactions	Lack of formal researcher-user interactions
	Infrastructure	
	Market structure	
Knowledge exchange (Farmer/ grower-researcher)	Actors	Lack of individuals in translator roles
	Institutions	Research culture of operating in disciplinary silos
		Lack of individuals in translator roles
		Research culture of hunting out next funding source
	Interactions	
	Infrastructure	
	Market structure	Fragmented advisory services

These findings, though focused on a subset of functions and structures within the wider systemic innovation policy framework, imply there is a need for 'systemic instruments' focused on enhancing multi-actor interaction, reducing institutional barriers (Smits and Kuhlmann 2004; Wieczorek and Hekkert 2012) and seeking complementarity among structural elements in the AIS. Examples of systemic instruments could be incentivising the development and participation of translators, and stimulating interactions among actors in fragmented value-chains. There is an emerging experience with systemic instruments in agriculture. Examples are organisations that broker and facilitate innovation between the multiple actors in value chains (enhancing vertical and horizontal coordination), and multi-actor platforms for innovation agenda setting and prioritisation in which all actors in the value chain and innovation support system (farmers, advisors, researchers, buyers, traders, retailers, policy makers, consumer representatives, interest groups) jointly articulate the innovation agenda (Klerkx and Leeuwis 2009; Klerkx and Nettle 2013). Organisations performing these functions are often not yet well recognized or resourced (Klerkx and Nettle 2013), with resourcing potentially drawing funding away from other functions (e.g. fundamental and applied science) in a constrained funding environment.

Conclusions

In the current New Zealand AIS there are key systemic challenges to the effective functioning of activities that support technology co-development (Table 1). Industry and industry bodies identified several systemic challenges to effective guidance of the search. The first was an absence of researchers who understood their business culture. Additional systemic challenges were vertically and horizontally fragmented market structures and a lack of strategic leadership in some industries. These were identified as significantly hindering effective guidance of the search, particularly in terms of identifying strategic actions needed to address industry challenges that spanned the value chain.

Several participants explicitly pointed to the recent Crown Research Institute Taskforce Review as leading to organisational changes that have improved interactions in knowledge development among research organisations and between research organisations and industry. However, remaining challenges to effective interaction between research organisations and knowledge users include ongoing competition for funding, an historic research culture of operating in disciplinary silos, and funding mechanisms that focused on academic evaluation criteria.

The majority of those interviewed from research organisations and industry highlighted that a key challenge to the effectiveness of the interaction between researchers and farmers/growers was a lack of individuals with the ability to operate as translators in knowledge exchange between, for example, science and farmers. These translator roles need to be established and incentivised in the New Zealand AIS to more effectively incorporate knowledge from multiple actors, such as farmers/growers, industry and policy, as well as science, in the innovation process. The challenge now is to identify system interventions to achieve this particular outcome as well as address other systemic challenges.

The study described here is part of a wider programme of system innovation (MIE 2012) to facilitate change in activities in the New Zealand AIS that effectively support technology co-development in the primary sector. The next step is to jointly develop a vision of the New Zealand AIS with the interviewees and collectively explore the application of a range of instruments across the primary sector to address the systemic challenges in Table 1. This will be undertaken through a series of workshops with the interview participants, and other key actors in the New Zealand AIS. The workshops will be repeated to jointly evaluate the extent to which systemic instruments have been implemented, are perceived to be addressing systemic challenges, and to collectively revise the application of systemic instruments over the life of this five year research programme. This process will enable the wider programme of system innovation to determine the importance of addressing various systemic challenges to enhance technology co-development.

Acknowledgements

We would like to acknowledge the Ministry of Business, Innovation and Employment which is funding the Primary Innovation project (CONT-30071-BITR-AGR) through a Biological Industries Targeted Research grant. A special thank you goes to the interview participants who kindly made themselves available to be interviewed. Neels Botha, Paula Blackett, Alison Dundass, Bruce Small and David Teulon provided invaluable input to the interview design. We received very useful feedback on earlier drafts of the paper from Liz Wedderburn, Margaret Brown and two anonymous reviewers.

References

Babbie E 2001, *The practice of social research,* 9th edn, Wadsworth/Thomson Learning, Belmont, CA

Beck N, Herman TJB and Cameron PJ 1992, 'Scouting for lepidopteran pests in commercial cabbage fields', in *Proceedings of the 45th New Zealand Plant Protection Conference*: 31-34.

Botha N, Coutts J and Roth H 2006, 'The role of agricultural consultants in the New Zealand Research, Development and Extension system', Paper presented at the New Zealand Agricultural and Resource Economics Society conference, Nelson, 24-235 August.

Bruges M and Smith W 2009, 'Improving utilisation of Maori land: Challenges and successes in the application of participatory approach', *Kotuitui: New Zealand Journal of Social Sciences Online*, 4(3): 205-220

Cameron PJ 2007, 'Factors influencing the development of integrated pest management (IPM) in selected vegetable crops: A review', *New Zealand Journal of Crop and Horticultural Science*, 35(3): 365-384

Crown Research Institute Taskforce 2010, *How to Enhance the Value of New Zealand's Investment in Crown Research Institutes,* Report of the Crown Research Institute Taskforce. Ministry of Business, Innovation and Employment, Wellington, <http://www.msi.govt.nz/>

Devaux A, Horton D, Velasco C, Thiele G, Lopez G, Bernet T, Reinoso I and Ordinola M 2009, 'Collective action for market chain innovation in the Andes', *Food Policy,* 34: 31-38.

Forester J 1999, *The deliberative practitioner: encouraging participatory planning processes*, The MIT Press, Cambridge, MA

Hartwich F and Negro C 2010, 'The role of collaborative partnerships in industry innovation: lessons from New Zealands's dairy sector', *Agribusiness*, 26(3): 425-449.

Hekkert MP, Suurs RAA, Negro SO, Kuhlmann S and Smits REHM 2007, 'Functions of innovation systems: A new approach for analysing technological change', *Technological Forecasting & Social Change*, 74: 413–432.

Hounkonnou D, Kossou D, Kuyper TW, Leeuwis C, Nederlof ES, Röling N, Sakyi-Dawson O, Traoré M and Van Huis A 2012, 'An innovation systems approach to institutional change: Smallholder development in West Africa', *Agricultural Systems*, 108: 74-83.

Holm P, Goodsite ME, Cloetingh S, Agnoletti M, Moldan B, Lang DJ, Leemans R, Moeller JO, Buendía MP, Pohl W, Scholz RW, Sors A, Vanheusden B, Yusoff K and Zondervan R 2013, 'Collaboration between the natural, social and human sciences in Global Change Research', *Environmental Science and Policy*, 28: 25-35.

Ingram J 2008, 'Agronomist-farmer knowledge encounters: an analysis of knowledge exchange in the context of best management practices in England', *Agriculture and Human Values,* 25(3):405-418.

Kamp LM, Smits REHM and Andriesse CD 2004, 'Notions on learning applied to wind turbine development in the Netherlands and Denmark', *Energy Policy,* 32: 1625–1637.

Klein Woolthuis R, Lankhuizen M and Gilsing V 2005, 'A system failure framework for innovation policy design', *Technovation,* 25: 609–619.

Klerkx L and Leeuwis C 2009, 'Operationalizing demand-driven agricultural research: Institutional influences in a public and private system of research planning in The Netherlands', *The Journal of Agricultural Education and Extension* 15(2): 161-175.
Klerkx L, Van Mierlo B, and Leeuwis C 2012, 'Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions' in I Darnhofer, D Gibbon and B Dedieu (eds.) *Farming Systems Research into the 21st century: the new dynamic*, Dordrecht, Springer, pp. 459-485.
Klerkx L and Nettle R 2013, 'Achievements and challenges of innovation co-production support initiatives in the Australian and Dutch dairy sectors: A comparative study', *Food Policy* 40:74-89.
Lundvall BA 1992, *National Systems of Innovation – Towards a Theory of Innovation and Interactive Learning*. Piner Publishers, London.
McEntee M 2010, 'More carrot and less stick: lessons from agricultural extension in New Zealand', in 8th World Congress of Participatory Action Research and Action Learning, 6th-9th September, Melbourne Australia, <http://www.alara.net.au/>
Merriam SB 2009, *Qualitative Research: A Guide to Design and Implementation*, Jossey-Bass, San Francisco.
Ministry of Business, Innovation and Employment 2012, *Co-learning and Co-innovation to Achieve Impact*, <http://www.msi.govt.nz/>
Ministry for Primary Industries 2011, Briefing for the Incoming Ministers, Ministry for Primary Industries, Wellington, <http://www.maf.govt.nz/Default.aspx?TabId=126&id=1262>
Ministry for Primary Industries 2012, *Survey of technlogy transfer services to farmers and growers in New Zealand*, Report by the Ministry for Primary Industries, Wellington.
Morriss S, Massey C, Flett R, Alpass F and Sligo F 2006, 'Mediating technological learning in agricultural innovation systems' *Agricultural Systems* 89(1):26-46
Neef A and Neubert D 2011, 'Stakeholder participation in agricultural research projects: a conceptual framework for reflection and decision-making', *Agriculture and Human Values*, 28: 179-194.
Nelson RR (ed.) 1993, *National Systems of Innovation: A Comparative Study*, Oxford University Press, Oxford.
Nieuwenhuis LFM 2002, 'Innovation and learning in agriculture', *Journal of European Industrial Training*, 26(6): 283-291.
QSR International 2012, *NVivo qualitative data analysis software*, QSR International Pty Ltd., Version 10
Pyke N 2011, 'Innovation and uptake of new technologies in the New Zealand arable industry', In *Proceedings of the 18th International Farm Management Congress*, Methven, Canterbury, New Zealand. <http://www.ifmaonline.org/>.
Röling N 2009, 'Pathways for impact: scientists' different perspectives on agricultural innovation', *International Journal of Agricultural Sustainability,* 7(2): 83-94
Smits R and Kuhlman S 2004, 'The rise of systemic instruments in innovation policy', *International journal of foresight and innovation policy*, 1: 4-32.
Spash C 2001. 'Editorial: broadening democracy in environmental policy processes', *Environment and Planning C*, 19: 475–481.
Suter WN 2012, *Introduction to Educational Research: A Critical Thinking Approach* (2nd edn), SAGE Publications, Los Angeles
Van Mierlo B, Leeuwis C, Smits R and Woolthuis RK 2010, 'Learning towards system innovation: Evaluating a systemic instrument', *Technological Forecasting and Social Change,* 77: 318-334.
Wieczorek AJ and Hekkert MP 2012, 'Systemic instruments for systemic innovation problems: Aframework for policy makers and innovation scholars', *Science and Public Policy*, 39: 74-87.
World Bank 2006, *Enhancing Agricultural Innovation: How to Go Beyond the Strengthening of Research Systems,* The World Bank, Washington D.C.