

Addressing complex challenges using a co-innovation approach: lessons from five case studies in the New Zealand primary sector

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Abstract: Co-innovation can be effective for complex challenges – involving complex interactions among multiple stakeholders, viewpoints, perceptions, practices and interests across programmes, sectors and national systems. However, there is limited systematic research on how co-innovation works in different projects. Approaches to challenges in the primary sector have tended to be linear, where tools and outputs are developed by a few, mostly scientists/researchers, and then extended to stakeholders. A co-innovation approach first deciphers and delineates the biophysical, societal, regulatory, policy, economic and environmental drivers, constraints and controls influencing these challenges at multiple levels. Secondly, stakeholder interactions and perspectives can inform and change the focus, as well as help in co-developing solutions to deliver agreed outcomes. Here we analyse the results of applying a co-innovation approach to five research projects in the New Zealand primary sector. The projects varied in depth and breadth of stakeholder engagement, availability of ready-made solutions, and prevalence of interests and conflicts. The projects show how and why co-innovation approaches in some cases contributed to a shared understanding of complex problems. Our results confirm the context-specificity of co-innovation practices.

1. Introduction

Understanding how innovation happens and ways research projects can be optimised to increase their innovation potential may enhance rates of adaptation (Hermans *et al.*, 2013) and adoption of technologies from research, science and technology investments. To address shortcomings in technology diffusion and uptake approaches there is increased focus on bringing together relevant agricultural sector actors in a coordinated, interactive fashion through co-innovation (Dogliotti *et al.*, 2014; Hall *et al.*, 2001; Klerkx *et al.*, 2012). Literature on agricultural innovation processes (e.g. Klerkx *et al.*, 2012; The World Bank, 2006) indicates an evolution and broadening of theoretical perspectives. Agricultural systems innovation processes differ from linear, technology-transfer-oriented approaches, being more evolutionary, multidisciplinary and multi-stakeholder approaches, and considering social, economic and institutional as well as technical changes (Klerkx *et al.*, 2012).

Co-innovation is an iterative process that brings together knowledge from many stakeholders, along with changes in technology, markets, regulations and other practices that support the commercialization and implementation of the knowledge to improve production, exports, profits and/or the environment (Garb & Friedlander, 2014; Klerkx *et al.*, 2012; Leeuwis, 2004; Röling, 2009). This process requires negotiation amongst previously unconnected stakeholders with competing values, worldviews, interests, planning horizons, incentives and accountability (Botha *et al.*, 2014; Johnson & Gregersen,

1995; Schut *et al.*, 2014). Co-innovation practice is context-specific and adaptive: how and when co-innovation is implemented must be tailored to the particular situation, and may change over time (Hall, 2005; Klerkx *et al.*, 2010; Neef & Neubert, 2011; Schut *et al.*, 2015). “Explicit or implicit choices are usually made as to who might take part” and “the question of who participates – as well as who is excluded and who exclude themselves – is a crucial one” (Cornwall, 2008, p.275), especially when the transaction costs associated with increased interactions among stakeholders outweigh perceived benefits (Ortiz *et al.*, 2013). While this is increasingly acknowledged, there is relatively limited comparative research unravelling how under a given overarching programme, different co-innovation projects may work differently (except, e.g., Seuneke *et al.* (2015)), although this is highly important to stimulate learning within a programme context (Thiele *et al.*, 2007).

These implementation differences are assessed in a large New Zealand (NZ) Government-funded research programme, Primary Innovation (PI), initiated in 2012 with two aims: i) implement and evaluate the effectiveness of co-innovation approaches in the primary sector (Botha *et al.*, 2014), and ii) identify barriers and enablers to co-innovation in the NZ primary sector (Turner *et al.*, 2016; Turner *et al.*, 2013). To achieve the first aim, the PI programme became involved in five NZ primary-sector research projects where attempts have been made to apply a co-innovation approach. Each of the projects applied nine principles of co-innovation that underpin and inform activity. These principles were adapted from Nederlof *et al.* (2011) and are presented at this conference by Coutts *et al.* (2016).

We focus on two co-innovation principles that were applied in practice across all innovation projects: i) take time to understand the problem from many different views; ii) be inclusive in terms of diversity of stakeholders. These principles were seen as those that could most affect a project’s focus and direction. We use interpretations of what constitutes innovation, following stylized innovation models articulated in Klerkx *et al.* (2012) to indicate the position of each project in the range from technology transfer to co-innovation in the Agricultural Innovation System (AIS). We also use Pretty’s (1995) typology of stakeholder participation to identify different types and degrees of participation reflecting the diversification of the projects’ goals and structures: i) manipulative participation; ii) passive participation; iii) participation by consultation; iv) participation for material incentives; v) functional participation; vi) interactive participation; vii) self-mobilization (Pretty, 1995). This typology has its constraints (Leeuwis, 2004; Neef & Neubert, 2011), but highlights the importance of genuine and meaningful participation. We argue that Pretty’s typology remains useful for analysis of the projects over time and across projects.

Three research questions primarily focusing on stakeholder involvement in problem definition in the research projects thus guided our analysis: i) Did the co-innovation process result in a change of problem definition? ii) If the definition had changed, to what extent can it be attributed to stakeholder involvement? iii) What were the barriers and opportunities to stakeholder participation shaping problem definition?

2. Innovation project descriptions

Three projects (Water use efficiency (WUE), Tomato potato psyllid (TPP) and Timber segregation) are led by research organisations; the other two (Heifer rearing and Nutrient management) are led by industry organisations. The projects started independently at different times, some before the PI programme started in October 2012, and some after. Each has progressed at a different rate because of various degrees of stakeholder involvement, a key part of co-innovation, and varying divergence of worldviews, interests, norms and values, planning horizons, incentives and accountability mechanisms of those involved (Botha *et al.*, 2014; Klerkx *et al.*, 2012).

We introduce the projects individually to provide context for the interactions taking place. The projects serve as case studies deliberately chosen to cover two interdependent characteristics of problems in NZ primary industries that influence the effectiveness of co-innovation: knowledge contestability (Andresen *et al.*, 2000); and a choice of mechanism for change; regulation (e.g. targets), market signals (e.g. pricing) and voluntary approaches (e.g. information distribution, extension, education) (Röling, 2009). None of the mechanisms for change function in isolation, but some have more influence in

certain circumstances than others. The five projects investigate problems ranging from where knowledge is uncontested to highly contested. Where knowledge is uncontested, the scope of the problem is well agreed, while with highly contested knowledge, different stakeholders view the problem scope differently. Knowledge becomes more contested at larger scales as the number of stakeholders increases and therefore competing values and perspectives and potential solutions also increase (Andresen *et al.*, 2000).

2.1 Water use efficiency

The aim of the WUE project is to improve on-farm irrigation decisions using better characterisation of current irrigation demands and accurate, accessible short-term weather forecasting. This project is being piloted on five NZ South Island farms within an irrigation scheme. The research and PI projects started in October 2012. The farmers are provided with farm-specific observed data on current rainfall, soil moisture, soil temperature, drainage and evapotranspiration, and region-specific 2-, 6- and 15-day rainfall forecasts (Srinivasan *et al.*, 2015). The data are shared with farmers in real-time via a dedicated website and as a daily email. Based on these data, farmers make informed irrigation application decisions. Annually, the farmers, irrigation scheme managers, researchers, and other relevant stakeholders (e.g. members of a local catchment committee, personnel from neighbouring irrigation schemes and regulatory and government agencies) meet to review the irrigation decisions made during the season. These meetings are a forum for sharing and discussing ideas, as well as reviewing and refining information provided. These workshops and other formal and informal meetings also refine and reshape the problem being addressed as well as the solutions achievable (Srinivasan *et al.*, 2016).

2.2 Tomato potato psyllid

TPP is a vector of the bacterium *Candidatus Liberibacter solanacearum* (CLso). This complex became a major problem in NZ potato crops in 2008. The aim of the TPP project is to assist the NZ potato industry to realise export growth by addressing the industry's pressing need for economically and environmentally sustainable control solutions for the TPP/CLso complex. The research project commenced in October 2013, with the PI programme becoming involved in June 2014. The research project entails fundamental research in three, mainly laboratory-based objectives (i) Sensory cues; ii) Population genetic variability, and iii) Host plant response), while the fourth objective is 'Knowledge transfer to stakeholders'. The science objectives each have an objective leader, while the fourth objective does not. Knowledge transfer was not planned until complete tools or knowledge were available (at project completion). Unlike in the other case studies, the innovation project leader is not the TPP research project leader.

2.3 Heifer rearing

The Heifer rearing project is a DairyNZ-led initiative focusing on the improvement of dairy herd reproductive performance by lifting the proportion of heifers entering the national herd at target live weight. Industry data indicated that 73% of such heifers are 5% or more below target (McNaughton & Lopdell, 2012). This represents a national loss of \$120M p.a. in dairy farm profit industry-wide (Brazendale & Dirks, 2014). The research project and PI commenced together in September 2013. The project initially formed a stakeholder industry advisory group which completed a causal analysis for understanding the influences on under-grown heifers in October 2013. Drivers and obstacles for improvement were identified; however, the number of farmer participants was proportionally low.

2.4 Nutrient management

The Nutrient management project focuses on activities on a network of Canterbury commercial farms, in NZ's South Island. This network is part of a large government-funded research programme combining the expertise and resources of three Crown Research Institutes, one University, and two industry-good bodies, and targets the twin challenges of reducing nitrate leaching and increasing profitability of arable, sheep and beef, and dairy farms. Experiments are conducted on pasture mixtures and crop sequences, and modelling of plant/soil and animal components as well as farm systems incorporating the options developed. While the topics are technical (Pinxterhuis *et al.*, 2015), the programme approach is based on co-innovation principles to achieve maximum uptake of these options (Edwards *et al.*, 2015). The

farmers' network is involved to co-develop the options with the research and development (R&D) community, test them on-farm and demonstrate to the wider community. The project started with the development of the research proposal from late 2012, incorporating co-innovation principles from the PI programme.

2.5 Timber segregation

The Timber segregation project is part of a larger government and industry co-funded programme. It aims to increase the value realised from existing forests through the development of cost-effective approaches to characterise and deal with variation in wood properties within and between trees (Moore & Cown, 2015). This will give wood processors increased confidence in the properties of the resource, so that more of the harvested resource is processed into added-value products, rather than exported as raw logs. The project started in October 2013, having been identified as a PI case study 12 months earlier. It thus deliberately set out to take a co-innovation approach during the proposal writing stage as well as during the project itself, particularly as a wide spectrum of views on the benefits of segregation was recognised. The specific research aim was developed through a series of workshops and roadshows with stakeholders from the forestry and wood-processing sectors including technical managers, executive managers, and staff from government and sector research organisations. Once the project funding was approved, the detail was revised with the industry co-funding partners. In addition to a governance group, an innovation cluster group has been formed whose membership includes researchers, forest growers, wood processors, industry associations and segregation tool manufacturers. This group meets annually to share ideas, discuss the research and develop a deepening understanding of problems and potential solutions.

3. Methods and analytical framework

To compare the five projects, the innovation project leaders, all biophysical scientists, and/or other project team members and a social science research team conducted a workshop in February 2016. The people most heavily involved in managing the projects and monitoring outcomes brainstormed the project goals, stakeholders and progress from the proposal stages to the present (February 2016; 2–3 years in for all projects). This paper uses data collected from the five individual projects, as well as personal experiences of the project teams and leaders. Each project was considered in relation to their type of stakeholder inclusion (Pretty, 1995) and their position on the AIS continuum from technology transfer to co-innovation, particularly project flexibility over time, on a scale of 1–5 (Klerkx *et al.*, 2012). This enabled comparisons in terms of project goals, structure and stakeholder involvement, and their effects on stakeholders' understanding of the problem and project focus to be determined.

4. How the innovation projects have changed

4.1 Innovation projects at proposal-writing stage

In all projects, stakeholders were involved at proposal-writing stage, giving formal and informal input (Table 1) (Pretty, 1995). The projects were also assessed for conceptual, organizational, and institutional features connected with theoretical perspectives on agricultural innovation (Table 2) (Klerkx *et al.*, 2012). Nutrient management and Timber segregation, and to a lesser extent Heifer rearing, used more of an AIS perspective at the proposal-writing stage than the other projects, which resulted in an opportunity to create a shared understanding of the problem and build trust.

Table 1: Status of the innovation projects at proposal writing stage: problem definition, stakeholder participation and engagement methods used.

Innovation project	Problem/project definition or focus	Type of stakeholder	Engagement methods	Stakeholder engagement (Pretty, 1995)¹
Water use efficiency	Improved irrigation and water use efficiency	Farmers, irrigation scheme, researchers	One-on-one meetings, phone calls	Passive participation
Tomato potato psyllid	Developing economically and environmentally sustainable control solutions for the TPP/CLso complex	Industry, some larger growers	Formal meetings, phone calls	Passive participation
Heifer rearing	Increase dairy farmers' profitability by increasing the number of heifers that meet liveweight targets pre-calving	Dairy farmers and graziers, industry, researchers, private companies	Advisory group meetings, farmer workshops, phone calls	Interactive participation
Nutrient management	Reduced nitrate leaching from arable, sheep & beef, and dairy farm systems	Researchers, industry	Formal meetings, workshops, email, one-on-one meetings, phone calls	Functional participation
Timber segregation	Improve the financial returns to growers and processors through better information on the wood properties of the forest resource	Growers, researchers, private companies	Formal meetings, workshops, roadshows, one-on-one meetings	Self-mobilisation

¹Stakeholder engagement types from minimal to maximum inclusion: 'passive participation' (people are informed about what is going to happen), 'participation by consultation' (people can give their own views), 'functional participation' (people participate by creating conditions that are favourable for an external project), 'interactive participation' (people participate in joint analysis and decide on follow-up) and 'self-mobilisation' (people take their own initiatives) (after Leeuwis, 2004).

Table 2: Analysis of the five innovation projects at proposal-writing stage using six characteristics of AIS (descriptions adapted from Klerkx *et al.*, 2012). Start dates are mentioned in project descriptions. Cell colour coding indicates the project's position on the AIS continuum from technology transfer (white) to co-innovation (dark grey with white letters); the darker the background, the greater the alignment of activities with AIS.

Innovation project	Water use efficiency	Tomato potato psyllid	Heifer rearing	Nutrient management	Timber segregation
Degree of stakeholder involvement	One-way flow of technology or knowledge from developer	One-way flow of technology or knowledge from developer	User and developer jointly define problem, then one-way flow of technology or knowledge from developer to user	User and developer collaborate in research and extension	User and developer collaborate in research and extension
Range of disciplines involved	Single discipline driven (e.g. agronomy)	Multidisciplinary (e.g. plus economics)	Multidisciplinary (e.g. plus economics)	Transdisciplinary (e.g. plus sociology and grower experts, with limited stakeholder involvement)	Transdisciplinary (e.g. plus policy makers, with broad stakeholder involvement)
Scope of the potential impact	Efficiency gains (input-output relationships)	Efficiency gains (input-output relationships)	Efficiency gains (input-output relationships)	Production unit-based livelihoods	Value chain, institutional change
Impact of stakeholder involvement	Technology packages	Modified packages to overcome constraints	Modified packages to overcome constraints	Joint production of knowledge and technologies	Joint production of knowledge and technologies
Driver	Supply-push from research	Supply-push from research	Supply-push from research	Responsiveness to changing contexts, patterns or interactions	Diagnose growers' constraints and needs
Position within the wider system	Aware but not engaged with policy/decision makers	Science not engaged with policy/decision makers	Aware but not engaged with policy/decision makers	Engaged with policy/decision makers	Aware but not engaged with policy/decision makers

4.2 Innovation projects now

In February 2016, the application of co-innovation principles in the projects had led to a re-shaping of the problem/project focus, except in the TPP project (Table 3), which is locked into contracted milestones with a Government funding agency, thus scored 'inflexible' in terms of capacity to reshape the problem (Table 4). All the projects moved more towards AIS in most categories over the period in which the co-innovation principles were applied (Table 4). The type of stakeholder and the engagement methods increased for all projects, except for TPP, since solutions are still under development through tightly managed research aims (Tables 1 and 3). Two barriers were identified for TPP. Firstly, the research project had already started before the PI team became involved, so co-innovation was introduced to project team members after traditional project development and delivery processes were established. Secondly, the PI team identified through interviews with key people that the intended knowledge exchange with stakeholders was seen as largely linear (Vereijssen *et al.*, 2015) and engagement awaits the production of technical solutions (e.g. resistant/tolerant cultivars). The PI team has offered support to deliver the knowledge transfer objective.

A significant change in stakeholder type and engagement happened in WUE and Heifer rearing. In WUE, a co-innovation approach was deliberately embedded at the start. Stakeholders were involved in evaluating the use of weather-forecast-based irrigation practices. Stakeholder views were sought through workshops and one-on-one meetings to ensure the processes and the resulting products were viable and practical. In Heifer rearing, the project leader DairyNZ proposed a series of regional focus groups in November 2013 to address the lack of farmer involvement with advisory groups. The purpose of these was to gain perspective and solutions from those who would implement them. The emphasis for the solution shifted as a result of these focus groups from a technical approach to increasing heifer live weight to emphasising the relationship between contract heifer graziers and stock owners. Focus groups identified key stakeholders as Beef+Lamb New Zealand and the Livestock Improvement Corporation. In response to the feedback, industry advisory group members were integrated into area-of-expertise working groups and a governance group for the project was established with key stakeholders.

Table 3: Status of the innovation projects after applying co-innovation principles: problem definition and stakeholder participation (February 2016).

Innovation project	Problem/project definition or focus	Type of stakeholder	Engagement methods	Stakeholder engagement (Pretty, 1995)
Water use efficiency	Improved irrigation, drainage, and water use efficiency	Farmers, irrigation scheme, researchers, regulatory bodies, non-pilot study farmers, farmers from other irrigation schemes, government	One-on-one meetings, phone calls, daily email updates, website, workshops, field days, Q&A sessions	Functional participation
Tomato potato psyllid	Developing economically and environmentally sustainable control solutions for the TPP/CLso complex	Industry	Formal meetings, email	Participation by consultation
Heifer rearing	Improve relationships and farm profitability for both dairy farmers and contract growers through heifers that meet liveweight targets pre-calving	Dairy farmers, graziers, industry, researchers, private companies	Focus groups, advisory groups, advisory panel	Interactive participation
Nutrient management	Reduced nitrate leaching from viable arable, sheep & beef, and dairy farm systems	Farmers, researchers, industry, policy/decision makers	Workshops, focus groups, email, one-on-one conversations, website, media releases, popular articles, conference presentations, journal articles	Self-mobilisation
Timber segregation	Improve the financial returns to growers and processors through better information on the wood properties of the forest resource	Wood processors, segregation tool manufacturers harvesting managers, log traders	Focus groups, newsletters, workshops	Self-mobilisation

Table 4: Analysis of the five innovation projects in February 2016 using six characteristics of AIS (descriptions adapted from Klerkx *et al.*, 2012). Project start dates are mentioned in project descriptions. Cell colour coding indicates the innovation project's position on the AIS continuum from technology transfer (white) to co-innovation (dark grey with white letters); the darker the background, the greater the alignment of activities with AIS.

Innovation project	Water use efficiency	Tomato potato psyllid	Heifer rearing	Nutrient management	Timber segregation
Degree of stakeholder involvement	User and developer collaborate in research and extension	One-way flow of technology or knowledge from developer to user	User and developer collaborate in research and extension	User and developer collaborate in research and extension	Co-develop innovation involving multi-actor processes and partnerships
Range of disciplines involved	Transdisciplinary (e.g. plus sociology and grower experts, with limited stakeholder involvement)	Multidisciplinary (e.g. plus economics)	Transdisciplinary (e.g. plus sociology and grower experts, with limited stakeholder involvement)	Transdisciplinary (e.g. plus sociology and grower experts, with limited stakeholder involvement)	Transdisciplinary (e.g. plus policy makers, with broad stakeholder involvement)
Scope of the impact	Efficiency gains (input-output relationships)	Production unit-based livelihoods	Production unit-based livelihoods	Production unit-based livelihoods	Value chain, institutional change
Impact of stakeholder involvement	Modified packages to overcome constraints	Modified packages to overcome constraints	Modified packages to overcome constraints	Joint production of knowledge and technologies	Joint production of knowledge and technologies
Driver	Responsiveness to changing contexts, patterns of interaction	Supply-push from research	Supply-push from research	Responsiveness to changing contexts, patterns or interactions	Diagnose growers' constraints and needs
Position within the wider system	Engaged with policy/decision makers	Science not engaged with policy/decision makers	Aware but not engaged with policy/decision makers	Engaged with policy/decision makers	Aware but not engaged with policy/decision makers
Flexibility in re-shaping problem (1=inflexible; 5=completely flexible)	5	1	5	3	5

5. Discussion

Changes in the projects described over time (Tables 2 and 4) suggest a shift in the spectrum towards increasing application of co-innovation principles. There can be a perception that using a co-innovation approach in research projects is more advanced because it is a newer development in social science thinking. However, when a problem is less complex and science can provide a simple solution, a technology-transfer method may be the simplest, most economically viable option, as organisational, and regional/state/national policy has little influence on improvements or outcomes. So depending on the problems' complexity, different approaches need to be chosen, defined as dynamic research configuration by Schut *et al.* (2014), or dictated by circumstances. The question for each project is which one(s) of the nine co-innovation principles (Coutts *et al.*, 2016) is/are most important to achieve change, and when should they be applied to best effect?

The extent and depth to which co-innovation principles were applied differed between projects. Here we discuss how implementing co-innovation approaches affected the first and second co-innovation principles: i) take time to understand the problem from many different views, and ii) be inclusive.

5.1 Did the co-innovation process result in a change of problem definition?

When evaluating the shift toward co-innovation, the projects most quickly able to change and adapt were Timber segregation, Nutrient management and Heifer rearing. In all three, the intent to apply co-innovation came before the establishment of project milestones and at the proposal-writing stage, in two cases (Timber segregation and Nutrient management) before funding confirmation.

Nutrient management has not seen changes in the problem definition as such, but because of the approach (Edwards *et al.*, 2015) and continued engagement of end-users (industry bodies and farmers in the network), some changes to the approach have been made and new R&D questions have been formulated. These guide the project activities, with an emphasis on integrating solutions in farm systems and supporting solution implementation on-farm. Similarly for Timber segregation, the up-front and ongoing engagement with end-users has resulted in changes in the approach to addressing the problem, rather than the problem definition itself. Within this project, the problem definition and approach are constantly revisited.

WUE has seen the most transformational change, with co-innovation principles becoming embedded in the project over four years rather than just before funding confirmation, as in Timber segregation, Nutrient management and Heifer rearing. WUE integrated flexibility by facilitating stakeholder interactions and bringing in additional stakeholders as necessary. The project expanded the stakeholders' thinking by looking for other opportunities (e.g. economic value of irrigation and drainage management) to enhance their farming, economically and environmentally.

For Heifer rearing, the application of the defined co-innovation principles did not influence every level of the project because the problem of under-grown heifers is not highly complex nor constrained by organisational/national policy.

TPP has faced the greatest challenge in integrating co-innovation, as PI became involved after project commencement. While the PI team may have a wider view of the activities required to address the TPP problem, milestones were written with a defined view of the science required.

Overall, the integration of co-innovation principles at the inception of a project accelerated uptake of the approach and improved responsiveness and buy-in, leading to better shared understanding of the problem and processes required to address it.

5.2 To what extent can the change in problem definition be attributed to stakeholder involvement?

Except for TPP, the type of stakeholders and engagement methods increased when co-innovation principles were adopted. Managing stakeholder participation is a time-consuming and ongoing process

mostly led by project leaders. In WUE, an external driver forced change in stakeholder behaviour and thinking. During the study, the regulatory authority introduced limits to on-farm water use and capped the amount of irrigation that can be lost as drainage. This provided an external policy stimulant for farmers to look for supporting technologies. The driver to adopt new practices thus changed from a research-based supply push to stakeholder demand to improve the ability to respond to emerging contexts.

In Heifer rearing, shifts in the problem definition were incremental, with wider stakeholder engagement and problem exploration having two effects: i) widening the base of stakeholders and organisations involved, and ii) redefining the scope and potential impact, from efficiency gains for dairy farmers to production livelihoods of contract graziers. Widening stakeholder engagement did not change the view of the problem, but confirmed its parameters. The apparent failure of earlier attempts to address problems associated with heifer rearing may be from a lack of emphasis on the relationship between stock owners and their contract graziers and mechanisms for optimising the business practices of both.

In Timber segregation, engagement was organised two-way, with science managers from Scion and industry research brokers involved in formally building support, and a small group of science leaders engaging with a wide range of forestry sector stakeholders to co-develop the scope of the proposed research. Stakeholder engagement had two broad aims: i) to develop an agreed science programme and ii) to build co-funding support.

5.3 What were the barriers and opportunities to stakeholder participation shaping problem definition?

Several project-specific barriers and opportunities were identified that hindered or enhanced the co-innovation process. The ability to respond to stakeholder feedback and insights and therefore the flexibility of the project is driven by individuals within projects (Röling, 2009), more so than the limitations or context of funding mechanisms. Project leaders' comfort with loosely defined milestones or their willingness to re-negotiate milestones with funding bodies has been the greatest influence on adaptability.

In Timber segregation, the industry could "adapt or die", so sector motivation for co-innovation was high; while in WUE, the social context shifted, providing an opportunity "too good to miss", with researchers and stakeholders "riding the wave" in response (project leader quotes). This leads to the question: "Does a co-innovation project have to be the source of innovation (creating new technologies or practices), or by applying co-innovation is it possible to adapt existing technologies and practices for application by engaging with the wider context?", resonating with ideas by Douthwaite *et al.* (2001). Hence, while co-innovation may have a different aim, it is always useful for adapting technologies to users' needs or for creating an enabling environment (see also Garb & Friedlander, 2014).

Overall, flexibility and adaptability, common themes across the projects, were important in achieving positive results from a co-innovation approach. However, the institutional setting and the ability to create the space and buy-in for co-innovation also mattered (see also Neef & Neubert, 2011).

6. Conclusion

Our experience confirms the context-specificity of co-innovation practices (e.g. Hall, 2005; Klerkx *et al.*, 2010; Schut *et al.*, 2015). By adopting at least the first two co-innovation principles when developing the proposal, or very early in the project, some projects have adapted to new knowledge brought by stakeholders. In some, the focus of the project was changed, and in others the approach taken to develop solutions changed. The willingness and ability of project leadership to engage with a range of stakeholders, to change project scope or its research approach, was crucial for continued stakeholder engagement. We conclude from our experience as biophysical innovation project leaders that to be successfully implemented, co-innovation requires an adaptable mind-set rather than strict adherence to a single method.

7. References

- Andresen, S., Skodivin, T., Underdal, A. & Wettestad, J. (2000). *Science and politics in international environmental regimes: Between integrity and involvement*. Manchester, Manchester University Press.
- Coutts, J., White, T., Blackett, P., Rijswijk, K., Bewsell, D., Park, N., Turner, J.A., Bewsell, D., Rijswijk, K. & Botha, C. (2016). *Evaluating a space for co-innovation. The application of nine principles for co-innovation in practice*. 12th European IFSA Symposium.
- Botha, N., Klerkx, L., Small, B. & Turner, J. A. (2014). *Lessons on transdisciplinary research in a co-innovation programme in the New Zealand agricultural sector*. *Outlook on AGRICULTURE* 43(3): 219-223.
- Brazendale, R. & Dirks, S. (2014). *What is the financial benefit of growing good young stock?* South Island Dairy Event, 23-25 June 2014, Invercargill, New Zealand.
- Cornwall, A. (2008). *Unpacking 'Participation': models, meanings and practices*. *Community Development Journal* 43(3): 269-283.
- Dogliotti, S., García, M. C., Peluffo, S., Dieste, J. P., Pedemonte, A. J., Bacigalupe, G. F., Scarlato, M., Alliaume, F., Alvarez, J., Chiappe, M. & Rossing, W. A. H. (2014). *Co-innovation of family farm systems: A systems approach to sustainable agriculture*. *Agricultural Systems* 126: 76-86.
- Douthwaite, B., Keatinge, J. D. H. & Park, J. R. (2001). *Why promising technologies fail: the neglected role of user innovation during adoption*. *Research Policy* 30(5): 819-836.
- Edwards, P., Pinxterhuis, J. B. & Bewsell, D. (2015). *Forages for reduced nitrate leaching – a cross sector approach*. *Proceedings of the 5th International Symposium for Farming System Design*: 291-292.
- Garb, Y. & Friedlander, L. (2014). *From transfer to translation: Using systemic understandings of technology to understand drip irrigation uptake*. *Agricultural Systems* 128: 13-24.
- Hall, A. (2005). *Capacity development for agricultural biotechnology in developing countries: an innovation systems view of what it is and how to develop it*. *Journal of international development* 17(5): 611-630.
- Hall, A., Bockett, G., Taylor, S., Sivamohan, M. V. K. & Clark, N. (2001). *Why research partnerships really matter: innovation theory, institutional arrangements and implications for developing new technology for the poor*. *World development* 29(5): 783-797.
- Hermans, F., Stuver, M., Beers, P. J. & Kok, K. (2013). *The distribution of roles and functions for upscaling and outscaling innovations in agricultural innovation systems*. *Agricultural Systems*, 115: 117-128.
- Johnson, B. & Gregersen, B. (1995). *Systems of innovation and economic integration*. *Journal of Industry Studies* 2(2): 1-18.
- Klerkx, L., Aarts, N. & Leeuwis, C. (2010). *Adaptive management in agricultural innovation systems: The interactions between innovation networks and their environment*. *Agricultural systems* 103(6): 390-400.
- Klerkx, L., van Mierlo, B. & Leeuwis, C. (2012). *Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions*. In I. Darnhofer, D. Gibbon & B. Dedieu (Eds.) *Farming systems research into the 21st century: The new dynamic* pp. 457-483. Dordrecht; Springer Netherlands.

- Leeuwis, C. (2004). *Communication for rural innovation: rethinking agricultural extension*. Oxford, Blackwell Science Ltd.
- McNaughton, L. R. & Lopdell, T. (2012). *Are dairy heifers achieving liveweight targets?* Proceedings of the New Zealand Society of Animal Production, Christchurch, New Zealand 72: 120-122.
- Moore, J. & Cown, D. (2015). *Wood quality variability – what is it, what are the consequences and what we can do about it?* *New Zealand Journal of Forestry* 59(4): 3-9.
- Nederlof, S., Wongtschowski, M. & Van der Lee, F. (2011). *Putting Heads Together. Agricultural Innovation Platforms in Practice*. Amsterdam, KIT publishers.
- Neef, A. & Neubert, D. (2011). *Stakeholder participation in agricultural research projects: a conceptual framework for reflection and decision-making*. *Agriculture and Human Values* 28(2): 179-194.
- Ortiz, O., Orrego, R., Pradel, W., Gildemacher, P., Castillo, R., Otiniano, R., Gabriel, J., Vallejo, J., Torres, O., Woldegiorgis, G., Damene, B., Kakuhenzire, R., Kasahija, I. & Kahi, I. (2013). *Insights into potato innovation systems in Bolivia, Ethiopia, Peru and Uganda*. *Agricultural systems* 114: 73-83.
- Pinxterhuis, J. B., Beare, M. H., Edwards, G. R., Collins, R. P., Dillon, P. & Oenema, J. (2015). *Eco-efficient pasture based dairy farm systems: a comparison of New Zealand, The Netherlands and Ireland*. *Grasslands Science in Europe* 20: 349-366.
- Pretty, J. N. (1995). *Participatory learning for sustainable agriculture*. *World Development* 23(8): 1247-1263.
- Röling, N. (2009). *Pathways for impact: scientists' different perspectives on agricultural innovation*. *International Journal of Agricultural Sustainability* 7(2): 83-94.
- Schut, M., Klerkx, L., Rodenburg, J., Kayeke, J., Hinnou, L. C., Raboanarielina, C. M., Adegbola, P. Y., van Ast, A. & Bastiaans, L. (2015). *RAAIS: Rapid Appraisal of Agricultural Innovation Systems (Part I). A diagnostic tool for integrated analysis of complex problems and innovation capacity*. *Agricultural Systems* 132: 1-11.
- Schut, M., van Paassen, A., Leeuwis, C. & Klerkx, L. (2014). *Towards dynamic research configurations: A framework for reflection on the contribution of research to policy and innovation processes*. *Science and public policy* 41(2): 207-218.
- Seuneke, P., Klerkx, L., De Wolf, P. & Rossing, W. A. H. (2015). *Transplantability of participatory agricultural research: the influence of institutional context in international programs*. *22nd European Seminar on Extension and Education, April 28-30 2015, Wageningen, The Netherlands*.
- Srinivasan, M. S., Bewsell, D., Jongmans, C. & Elley, G. (2016). *Just-in-case to justified irrigation: Applying co-innovation principles in an irrigation scheme*. 12th European IFSA Symposium.
- Srinivasan, M. S., Elley, G. & Bewsell, D. (2015). *Co-innovation for water management in New Zealand*. *GLP News* 11: 16-18.
- The World Bank 2006. *Enhancing agricultural innovation: How to go beyond the strengthening of research systems*. Washington, DC, USA, The World Bank.
- Thiele, G., Devaux, A., Velasco, C. & Horton, D. (2007). *Horizontal evaluation: Fostering knowledge sharing and program improvement within a network*. *American Journal of Evaluation* 28(4): 493-508.

Turner, J. A., Klerkx, L., Rijswijk, K., Williams, T. & Barnard, T. (2016). *Systemic problems affecting co-innovation in the New Zealand Agricultural Innovation System: Identification of blocking mechanisms and underlying institutional logics*. *NJAS-Wageningen Journal of Life Sciences* 76: 99-112.

Turner, J. A., Rijswijk, K., Williams, T., Barnard, T. & Klerkx, L. (2013). *Challenges to effective interaction in the New Zealand agricultural research and extension system: an innovation systems analysis*. *Extension Farming Systems Journal* 9(1): 89-98.

Vereijssen, J., Park, N. M., Agnew, N. & Williams, T. (2015). *A case study on the role of co-innovation in tomato potato psyllid/zebra chip research in New Zealand*. 2015 APEN Conference, 10-12 November 2015, Adelaide, South Australia.

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