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# Innovation and networks in New Zealand farming

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The New Zealand government seeks to dramatically increase the value of agricultural exports while concurrently protecting the natural environment. Thus, farmers are expected to adopt pro-environmental management practices and novel farm technologies. We show that farmers are more likely to adopt new practices and technologies after seeing them demonstrated, but earlier evidence indicates that demonstration is most effectively undertaken within farmer networks. We use multivariate regression to identify the traits of livestock farmers who are innovative by focusing on adoption of pro-environmental management practices (managing nutrients, soils and pugging) and novel farm technologies (e.g., windmills, computer-based management systems, automatic sensors and specialised grasses), considering both numbers adopted and timing. We find that dairy farmers are more innovative than other livestock farmers and that higher education levels and stronger environmental norms within the family are strongly associated with innovativeness. In addition, we find that innovators and early adopters have larger networks than other farmers. Moreover, the composition of these networks is much more varied than the networks of less innovative farmers. These findings imply that innovative farmers in New Zealand may also act as connectors for the diffusion of new ideas in farming.

**Key words:** best management practices, connectors, dairy, diffusion, Survey of Rural Decision Makers, technology adoption.

## 1. Introduction

The New Zealand government has ambitious plans to double primary industry exports in real terms from \$32 billion in 2012 to \$64 billion by 2025 and to increase the value of exports from 30 per cent to 40 per cent of the share of real GDP (Ministry of Business, Innovation, and Employment, MBIE 2015). Achieving these targets will require the value of primary industries to grow at 5.5 per cent annually (assuming global price for primary exports remain stable), and as such, New Zealand farmers are being tasked with converting land to higher value production, adding land to productive primary industries, and/or intensifying existing farming operations.

However, farmers also face increasing pressure to limit the environmental impacts of farming. For example, the United Nations Climate Change Conference in Paris set a target of holding the increase in global average temperature to below 2°C above pre-industrial levels, and the New Zealand Ministry for the Environment has set a target of reducing greenhouse gas

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emissions to 30 per cent below 2005 levels by 2030. Currently, agriculture is the largest contributor of greenhouse gases (OECD 2017), and emissions from the sector must fall if the target is to be achieved, posing a specific challenge to farmers, particularly in the light of falling dairy prices.

Furthermore, farmers face strong environmental standards. The Resource Management Act of 1991 (hereafter, 'RMA') is the main piece of legislation to address the effects of economic activity on environmental outcomes, and it charges regional councils (the equivalent of state governments) with preparing regional policy statements and regional plans, both of which set the direction for sustainable management of natural resources. Regional policy statements and regional plans commonly stipulate that regional councils will engage with the public and stakeholders in setting environmental policy, will lead public education and awareness of environmental policy, will undertake environmental research and monitoring, and will provide advice and support to farmers for implementing new practices and technologies. Within the RMA framework, farmers are regulated through regional plans and the requirement to obtain consents, posing a second challenge to farmers. Although budgets for extension services have eroded significantly at both the regional and central government levels, most regional councils retain land management advisors and promote pro-environmental management practices at regional A&P fairs and/or field days.

The Local Government Act of 2002 further stipulates that regional councils must promote both environmental and economic well-being of communities. As such, regional councils champion the implementation of pro-environmental management practices and the adoption of new technologies for farm management. Empirically, diffusion of new ideas is facilitated through successful demonstration, and studies in New Zealand and elsewhere have found that demonstration is most effective when delivered by trusted individuals (Morgan *et al.* 2015).

However, Blind (2006) notes that public trust in government and political institutions has been falling in advanced industrialised democracies since the 1960s, and Small *et al.* (2016) show that farmers in New Zealand mistrust regional councils, ranking regional councils 16th out of 17 sources of information in terms of the trustworthiness of farming advice that they provide, higher than television but below the Internet, radio, print media and the central government. Such mistrust presents a potential hurdle for the diffusion of information as local government has been shown to be a more effective champion of new practices than central government (Scholz and Wang 2006).

In New Zealand, other farmers, scientists, and veterinarians are the three most trusted sources of information for farmers (Small *et al.* 2016). Diederer *et al.* (2003) note that farming tradition and cooperation contribute to trust among farmers, and Sligo and Massey (2007) explain that trust is particularly strong among New Zealand dairy farmers due to a lack of price competition because virtually all dairy farmers are members of cooperatives in which the same payment per unit of output is paid to each member. This finding likely

holds for livestock farmers more generally as the country is a price taker for exports and as the sales of one livestock producer has no impact on the prices obtained by another livestock producer. By not competing directly for international markets, there is no downside to information sharing, and through mutual cooperation, personal trust increases (Acedo-Carmona and Gomila 2014). Hence, other farmers are trusted more than regional councils even if regional councils have greater expertise (Kromm and White 1991; Rosenberg and Margerum 2008).

Governments may nevertheless promote accelerated adoption of good practices and new farming technologies by encouraging diffusion through professional networks (Wu and Zhang 2013) in which innovative individuals find new approaches and those with strong social networks encourage widespread uptake. Rogers (2003) outlines a typology of innovation based on timing: specifically, 'innovators' (who comprise the first 2.5 per cent of the population to adopt a technology) and 'early adopters' (the next 13.5 per cent) pioneer new practices. 'Connectors' (Gladwell 2002; Degen 2010) – that is, individuals with large personal networks – are thus well positioned to diffuse innovative practices even if they are not among the first to adopt them (Andreoli and Worchel 1978; Carr and Tait 1990). If trusted connectors with large networks cooperate with innovators and early adopters, diffusion rates will increase.

Most existing studies on innovation focus on current adoption (e.g., Wheeler 2008; Huang *et al.* 2011), although a minority use recall data to understand the timing of adoption (e.g., Bergström 2015). Consider the case of organic farming: Burton *et al.* (2003) find that farmers who are more concerned about the environment and who are female are more likely to adopt organic farming practices. Wheeler (2008) finds a quadratic effect for age in that both younger and older people are more open to organic farming. In addition, tertiary education, higher levels of knowledge about organic farming, and working in natural resource management lead to a greater openness to adoption. Contrastingly, professionals who have worked in their fields for a long time or who work in broadacre or grazing industries are significantly less likely to adopt organic practices.

Padel (2001) notes that early adopters of organic farming share many traits with early adopters of other pro-environmental technologies. To wit, Diederer *et al.* (2003) find that larger farms, farms from more heterogeneous markets, younger farmers, and farmers who value external information are more likely to implement innovative technologies in Holland. Dairy farmers are less likely to adopt than farmers in other industries. Similarly, Läpple and van Rensburg (2011) find that younger farmers and more environmentally oriented farmers are more likely to adopt pro-environmental practices, that nonadopters exhibit little desire to seek information about new practices and that laggards show higher levels of information seeking than early adopters. Outside of agriculture, Huang *et al.* (2011) and Bergström (2015) show that youth, high levels of education, white collar (Bergström 2015) and expert knowledge (Huang *et al.* 2011) lead to higher rates of new nonfarm technologies.

Profitability does not seem to be a main driver in the adoption of pro-environmental management practices (Michel-Guillou and Moser 2006; Läßle and van Rensburg 2011). Instead, norms and perceptions of social pressure influenced by the social milieu influence planned behaviours (Ajzen 1991) as do attitudes towards adoption of new practices (Walford 2003; Burton 2004). External social pressures, such as pressure from consumers (Anton *et al.* 2004) or desire to raise one's public image (Michel-Guillou and Moser 2006), can lead firms to adopt pro-environmental management practices. Pressure from regulatory boards also drives firms to adopt environmental standards (Anton *et al.* 2004; Horbach 2008).

There is also a nascent literature on social networks and the adoption of pro-environmental farming practices and novel farm technologies. For example, Linder *et al.* (1982) look at the distance to sources of innovation to explain whether or not farmers will adopt new technologies, finding that greater distance (i.e. weaker networks with innovators) is associated with longer lags to adoption. Likewise, Ward and Pede (2015) find that geographically closer network members have more influence on adoption decisions than more distance network members. Wossen *et al.* (2013) similarly find that farmers whose land abuts innovators' land are more likely to adopt pro-environmental management practices, although they also find that increased distance between network members has a positive effect on adoption. Burton *et al.* (2003) find that UK farmers who switched to organic farming have networks that are dominated by other farmers while conventional farmers' networks skew towards extension officers and others from the Agricultural Development and Advisory Service. Brown *et al.* (2016) show that experience, gender, and education are positively correlated with network size in the New Zealand context, although Warriner and Moul (1992) show that factors such as age, education, and belief in the effectiveness of conservation tillage are much stronger predictors of adoption of conservation tillage than social networks.

The findings of the studies discussed above are often inconsistent or incomplete. Moreover, they stem largely from Europe, North America, and the developing world, with limited evidence from Australasia. Hence, we seek to apply a novel data set to the New Zealand context to identify the characteristics of farmers who are comparatively innovative and to interrogate the network size and composition of innovators and early adopters vis-à-vis late adopters and laggards. Specifically, we use the 2015 Survey of Rural Decision Makers (Brown 2015) to establish that demonstration spurs adoption of pro-environmental management practices and novel farming technologies among livestock farmers in New Zealand. We then use count models of these pro-environmental management practices and novel farm technologies and maximum-likelihood estimation on the timing of adoption to identify characteristics of innovators. Next, we use a count model to identify characteristics of farmers with large social networks and subsequently analyse the composition of farming networks among different classes of farmers. We find that adoption of pro-environmental management

practices and novel farm technologies is pronounced in the New Zealand dairy industry. It is also marked by higher education levels and stronger environmental norms within farmers' families. Experience affects the timing of adoption but not the number of practices or technologies adopted, and male respondents are more likely to have adopted novel farm technologies. Moreover, we find that network size increases with these measures of innovativeness and that network composition becomes more cosmopolitan as innovativeness increases.

In the next section of the paper, we describe the Survey of Rural Decision Makers and the methods employed in its analysis. Next, we describe three sets of results for demonstration, innovativeness, and connectedness. The final section concludes.

## **2. Materials and methods**

### **2.1 Survey of Rural Decision Makers**

The empirical analysis is based on the 2015 Survey of Rural Decision Makers (Brown 2015), a large, Internet-based survey that covers both commercial production and lifestyle farming in all 16 regions in New Zealand. The survey consists of 288 questions, including detailed information on demographics; values; land use and land-use change; farm management; objectives; and network size and composition.

The sampling strategy relied primarily on contacting farmers via email through the National Animal Identification and Tracing database, industry and sector group membership lists, and a list of individuals who responded to the 2013 Survey of Rural Decision Makers (Brown 2013). Industry and sector groups that circulated information about the survey among their members included Beef + Lamb New Zealand, the Farm Forestry Association, Federated Farmers, the Foundation for Arable Research, Horticulture New Zealand, New Zealand Wine, the QEII Charitable Trust, and Rural Women. In addition, invitations to participate in the survey were posted by mail to approximately 40 per cent of all commercial farmers in the Statistics New Zealand business registry. Invitations were personalised, and unique URLs were sent to each address to facilitate sending of reminder messages to nonrespondents. A \$10 donation was made to charity for each completed survey, and all survey participants were entered into a prize draw for one of five prepaid visa cards. The survey took 27 minutes to complete, on average.

One criticism levied against online surveying is lack of accessibility, particularly for rural populations. However, approximately 80 per cent of rural New Zealanders had home access to broadband in 2015 (a figure that is rapidly expanding under the government's Rural Broadband Initiative). In total, 2839 respondents completed the survey, including 1984 commercial farmers. The sample of commercial farmers closely approximates the population reported in the 2012 agricultural census by geography, industry



and farmer age, although sheep and/or beef farmers and farmers from Auckland and Wellington are slightly over-represented and foresters and farmers from Waikato are slightly underrepresented; our inferential analysis thus accounts for industry, region and demographics.<sup>1</sup>

Because lifestyle farmers are unlikely to be involved in achieving the export goals established by the government and because many management practices and technologies are irrelevant to this subgroup, the analysis is restricted to commercial farming. In addition, because pro-environmental management practices do not apply equally to all primary industries (e.g. because plans to reduce pugging are not relevant for fruit producers or foresters), we further restrict the sample to livestock producers.

Table 1 shows summary statistics of the variables of interest. Respondents' likelihood of adopting an idea after a successful demonstration is measured on an 11-point scale from 0 (strongly disagree) to 10 (strongly agree) in response to the statement, 'After I see new practices successfully demonstrated by other farmers, I am more likely to adopt them'. A strong stated preference for demonstration is evident, with a mean score of 6.6.

We use two different proxies for innovativeness. The first is the number of pro-environmental management practices that have been adopted by each respondent; because our sample is restricted to livestock farmers, these desirable practices include implementation of specific plans for managing nutrients, soils and pugging.<sup>2</sup> This measure therefore varies between 0 and 3, with a mean of 1.1. The second measure of innovativeness is the number of 'novel' technologies that have been adopted on respondents' farms. These technologies that are making inroads in New Zealand farming include windmills for generating electricity, computer-based management systems, automatic sensors and/or lysimeters, and lucerne and/or plantain grasses. The mean number of novel farm technologies is 0.5, with a standard deviation of 0.8.<sup>3</sup> We also assess innovation by considering the timing of adoption.

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<sup>1</sup> Sample selection bias is a concern if more innovative farmers are disproportionately likely to participate in the survey. However, as shown below, we find that fewer farmers belong to the 'innovators' group (based on the number of pro-environmental management practices that have been adopted) than Rogers (2003) and others.

<sup>2</sup> A nutrient management plan describes how specific plant nutrients (including nitrogen and phosphorous) are managed to increase productivity, minimise costs and reduce the risk of water pollution. On New Zealand livestock farms, soil management plans emphasise conservation tillage, shelterbelts for reducing wind erosion, avoiding overworking of soils and maintaining vegetative cover. Pugging results from soil pores filling with water, causing a 'slurry' surface and damaging soil and pasture. It is a common problem on New Zealand sheep, beef, dairy and deer farms. Even so, adoption of pro-environmental management practices is far from universal, even when they may ultimately be cost neutral (e.g. Kaine 2015).

<sup>3</sup> While we believe that these measures are indicative of innovativeness, they may also be interpreted more generally as 'willingness to adopt recommended management practices'. The percentage of revenue from innovative products and services is also used to define innovativeness by the New Zealand MBIE. Unfortunately, we are unable to link individual respondents in the Survey of Rural Decision Makers with individual respondents from MBIE's Business Operations Survey, so we are unable to evaluate this alternative definition.

**Table 1** Summary statistics

Variable	Unit	Mean	SD
Preference for demonstration	0–10	6.600	1.690
Number of management practices	#	1.060	1.040
Number of novel farm technologies	#	0.473	0.753
Network size	#	8.960	23.9
Male	1/0	0.747	0.435
Farming experience	Years	29.0	14.2
Secondary or below	1/0	0.385	0.487
Certificate	1/0	0.114	0.318
Diploma	1/0	0.182	0.386
Bachelor's/postgraduate	1/0	0.273	0.446
Master's or above	1/0	0.046	0.210
Dairy	1/0	0.297	0.457
Sheep/beef	1/0	0.656	0.475
Deer	1/0	0.031	0.172
Other stock	1/0	0.028	0.166
Family expectations	0–10	6.900	2.110
Community expectations	0–10	6.840	1.920
Public expectations	0–10	7.700	1.790
Auckland	1/0	0.045	0.207
Bay of Plenty	1/0	0.050	0.219
Canterbury	1/0	0.146	0.353
Hawkes Bay/Gisborne	1/0	0.084	0.277
Manawatu	1/0	0.118	0.323
Northland	1/0	0.085	0.279
Otago	1/0	0.079	0.270
Southland	1/0	0.071	0.256
Taranaki	1/0	0.052	0.222
Tasman/Nelson/Marlborough	1/0	0.049	0.215
Waikato	1/0	0.151	0.359
Wellington	1/0	0.050	0.219
West Coast	1/0	0.020	0.139

Note: The unit describes how each variable is measured. “0–10” indicates a scale. “1/10” indicates a dummy variable.

Connectedness is measured via the total size of professional networks. Specifically, respondents were asked to report the number of individuals with whom they regularly met to discuss farm finances or environmental performance during the previous 12 months in each of the following groups: farmers in the same industry, farmers in other industries, scientists, government, cooperatives and industry groups, accountants/financial advisors, rural retailers/fertiliser representatives, and iwi (i.e., groups of Māori that have specific claims to natural assets through the Treaty of Waitangi). The mean network size is 9.0, although the distribution is right-skewed as one-third of the respondents did not discuss farm finances or environmental performance with anyone outside the farm/family and 1 per cent met with 100 or more individuals.

In this subsample, 74.7 per cent of respondents are male, and the average years of experience is 29.0. More than 60 per cent have postsecondary qualifications, most often a Bachelor's degree (27.3 per cent), diploma (18.2 per cent), or certificate (11.4 per cent). Nearly two-thirds of the respondents



in this subsample are sheep and/or beef farmers, including raising prime cattle and bull beef. Although mixed-usage farming is widespread in New Zealand, 29.7 per cent of the respondents identify themselves as primarily belonging to the dairy industry. The remaining farmers in the sample identify as deer farmers (3.1 per cent) or farmers who raise other classes of livestock (2.8 per cent).

To assess norms and social pressure, respondents were asked to evaluate the extent to which their families, the farming community, and the New Zealand public ‘expect me to manage my farms in an environmentally friendly way’. Respondents evaluated these three statements on a scale from 0 (‘strongly disagree’) to 10 (‘strongly agree’). Respondents perceive the perceptions of the New Zealand public to be strongest with a mean of 7.7, followed by family (6.9) and the farming community (6.8).

## 2.2 Econometric methods

To evaluate the determinants of adoption of pro-environmental management practices and novel farm technologies (both count variables), we estimate a negative binomial model as follows:

$$Prob[Y = y_i | x_i] = \frac{\Gamma(\theta + y_i) r_i^\theta (1 - r_i)^{y_i}}{\Gamma(1 + y_i) \Gamma(\theta)}, \forall i = 1, \dots, N,$$

where  $y_i$  is the count of pro-environmental management practices or novel farm technologies adopted by respondent  $i$ .  $x$  is a set of explanatory variables including gender, experience, education, industry, community norms and region.  $\theta > 0$  and  $r_i = \theta / (\theta + \lambda_i)$ , where  $\lambda_i = \exp(\alpha + x_i' \beta)$ .

We also consider the timing of adoption as an indicator of innovativeness. We first tested for sample selection bias using a Heckman probit model. In our estimates, we could not reject the hypothesis that  $\rho = 0$  (i.e. that there is no correlation between the error terms of the first and second stages of the model) or that  $\lambda = 0$  (i.e. that the selection correction term is zero). Thus, we pursue probit estimation without selection, an estimator that is consistent (van de Venn and van Praag 1981; Johnston and DiNardo 2000).

Specifically, we use an ordered probit model to account for the fact that the time of adoption is reported categorically in the survey. Consider a latent continuous metric  $y_i^*$  such that it is a function of  $x_i$ :

$$y_i^* = \beta x_i + e_i, \quad e_i \sim N(0, 1), \forall i = 1, \dots, N.$$

The observable  $y_i$  are bound by unknown threshold parameters ( $\mu$ ), estimated by  $\beta$  such that

$$y_i = 0 \text{ if } y_i^* \leq 0,$$

$$y_i = 1 \text{ if } 0 < y_i^* \leq \mu_1,$$

$$y_i = 2 \text{ if } \mu_1 < y_i^* \leq \mu_2,$$

$$y_i = 3 \text{ if } \mu_2 < y_i^* \leq \mu_3,$$

on a four-point scale: 0 (did not implement), 1 (implemented 0–2 years ago), 2 (implemented 2–5 years ago) and 3 (implemented over 5 years ago). We consider farmers who adopted pro-environmental practices and/or novel farm technologies longer ago as being more innovative.

Connectedness is measured via both network size and composition. Preferences for demonstration are measured via agreement with the statement ‘After I see new practices successfully demonstrated by other farmers, I am more likely to adopt them’. Connectedness is also analysed via a count model of the number of individuals in one’s professional network as described above.

### 3. Results

#### 3.1 Demonstration

Respondents report being more likely to adopt pro-environmental management practices and novel farm technologies after seeing a successful demonstration. This statement is evaluated on a 0–10 scale, with a mean of 6.6 and 91 per cent of respondents selecting a score of 5 or higher.

#### 3.2 Adoption of pro-environmental management practices and novel farm technologies

Rogers (2003) identifies the first 2.5 per cent to adopt a new technology as innovators, the next 13.5 per cent as being early adopters, and the remaining population as being split between the ‘late majority’ and ‘laggards’. In our data, 11 per cent of farmers have adopted three pro-environmental management practices (out of three considered); 25 per cent have adopted two pro-environmental management practices; 24 per cent have adopted one pro-environmental management practice; and the remaining 40 per cent have not adopted any of the three management practices. Similarly, 2.3 per cent of

our sample has adopted three or more novel farm technologies (out of four considered); 8.8 per cent has adopted two novel farm technologies; 23 per cent has adopted one novel technology; and 66 per cent has not adopted a novel technology. We thus consider respondents who have adopted three or more novel farm technologies to be innovators and those who have adopted two novel farm technologies to be early adopters in the sense of Rogers (2003), although we note that these shares are somewhat more conservative than those specified by Rogers (2003). We further consider those who have implemented three pro-environmental management practices as being innovators and those who have implemented two pro-environmental management practices as being early adopters even though these shares are more liberal than those suggested by Rogers (2003).

Table 2 reports the determinants of the number of pro-environmental management practices and the number of novel farm technologies adopted using a Poisson model. Explanatory variables include gender, experience, education, industry and community norms. Region dummies are included as additional regressors to control for differing weather, soil types and other factors.<sup>4</sup>

Coefficients are interpreted as follows: for a one unit change in each regressor, the difference in the logs of expected counts of the regressand is expected to change by the regression coefficient, *ceteris paribus*. For instance, for each additional point on the 0–10 scale for family environmental expectations, farmers are expected to have implemented  $e^{(0.0275)} = 1.03$  additional desirable practices and to have adopted  $e^{(0.0388)} = 1.04$  additional novel farm technologies, *ceteris paribus* ( $P < 0.10$ ). Dummy variables are interpreted vis-à-vis the omitted categories, that is female, secondary qualification or less, and dairy farming.

While nutrient management, soil preservation and pugging potentially concern all livestock farmers, dairy farmers are predicted to implement 1.57–2.52 more pro-environmental management practices than other farmers ( $P < 0.01$ ). Part of dairy farmers' apparent enthusiasm for implementing such practices likely stems from the Dairying and Clean Streams Accord of 2003, which lists nutrient management planning as a condition of supply to the largest dairy cooperative (Fonterra 2007). Dairy farmers are also predicted to have adopted more novel farm technologies than sheep and beef farmers ( $P < 0.01$ ) – perhaps because the price for dairy milk solids more than doubled between 2005 and 2014 – but not more than deer farmers and other livestock farmers. This finding contradicts Diederer *et al.* (2003), who find that Dutch dairy farmers are less likely to be either innovators or early adopters than farmers in other industries.<sup>5</sup>

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<sup>4</sup> Results for regions are available from the authors but are not reported here to shorten the table.

<sup>5</sup> Diederer *et al.* (2003) note that this result could stem from unique regulations of the European dairy industry.

**Table 2** Poisson estimates of number of pro-environmental management practices and novel farm technologies adopted

	Number of pro-environmental management practices	Number of novel farm technologies
Male	0.0432 (0.77)	0.335*** (3.61)
Farming experience	0.00225 (1.24)	0.0000319 (0.01)
Certificate	0.0510 (0.62)	0.346*** (2.81)
Diploma	0.0877 (1.30)	0.454*** (4.50)
Bachelor's/postgraduate	0.141** (2.25)	0.348*** (3.55)
Master's or above	0.247** (2.19)	0.520*** (3.15)
Sheep/beef	-0.451*** (-7.91)	-0.331*** (-3.68)
Deer	-0.888*** (-4.94)	-0.295 (-1.45)
Other stock	-0.923*** (-4.94)	-0.227 (-1.03)
Family environmental expectations	0.0275** (2.02)	0.0388* (1.86)
Community environmental expectations	0.0234 (1.37)	-0.00147 (-0.06)
Public environmental expectations	0.00337 (0.19)	0.0231 (0.87)
Constant	0.113 (0.58)	-2.310*** (-5.97)
Region dummies	Yes	Yes
Observations	1338	1338
Chi-square test for $\alpha = 0$ ( $P$ -value)	1.000	0.500

Notes:  $z$  statistics in parentheses.

Pro-environmental management practices include plans for managing nutrients, soils and pugging. Novel farm technologies include windmills for generating electricity, computer-based management systems, automatic sensors and/or lysimeters and lucerne and/or plantain grasses. Female, secondary schooling and below and dairy are omitted categories.

\* $P < 0.10$ ; \*\* $P < 0.05$ ; \*\*\* $P < 0.01$ .

Education is positively associated with adoption of both pro-environmental management practices and novel farm technologies: university-educated farmers have adopted more pro-environmental management practices than farmers with secondary educations or less ( $P < 0.05$ ) and have adopted more novel farm technologies ( $P < 0.01$ ). For example, farmers with masters degrees or higher are predicted to have adopted 1.28 more pro-environmental management practices and 1.72 more novel farm technologies than farmers with secondary education or less. These results are consistent with Wheeler's (2008) findings that tertiary education is positively associated with the adoption of organic farming.

Environmental expectations within the farming family are positively associated with implementation of pro-environmental management practices ( $P < 0.05$ ) and adoption of novel farm technologies ( $P < 0.10$ ), and male respondents are predicted to have adopted 1.40 more novel farm technologies than female respondents, *ceteris paribus*. The effect of experience on these measures of innovativeness is not statistically distinguishable from zero.

Table 3 reports estimates for when each of three pro-environmental management practices were implemented and when each of four novel farm technologies were adopted, if at all, using ordered probit estimation. The latent dependent variable is categorised as never having adopted, adopting within the previous 2 years, adopting 2–5 years ago and adopting 5 or more

Table 3 Ordered probit estimates for the timing of implementation

	Nutrient management plan	Soil management plan	Pugging management plan	Windmill electricity generation	Computer-based management	Automatic sensors	Lucerne and/ or plantain
Male	-0.0587 (-0.69)	0.0302 (0.33)	0.115 (1.40)	-0.224 (-1.52)	0.421*** (4.02)	0.438*** (2.78)	0.199** (2.24)
Farming experience	0.00420 (1.49)	0.00586** (2.00)	0.0113*** (4.31)	-0.00803* (-1.66)	-0.00114 (-0.36)	0.00265 (0.53)	0.00601** (2.16)
Certificate	-0.153 (-1.19)	0.114 (0.86)	0.230* (1.92)	0.0265 (0.11)	0.405*** (2.98)	0.304 (1.36)	0.0761 (0.62)
Diploma	0.00577 (0.06)	0.160 (1.47)	0.243** (2.41)	0.361* (1.93)	0.286** (2.37)	0.480*** (2.67)	0.346*** (3.45)
Bachelor's degree/ postgraduate	0.0708 (0.75)	0.244** (2.41)	0.161* (1.76)	0.182 (1.01)	0.423*** (3.84)	0.542*** (3.23)	0.0681 (0.70)
Master's degree or above	0.218 (1.23)	0.563*** (3.15)	-0.0174 (-0.10)	0.282 (0.95)	0.455** (2.27)	0.595** (2.00)	0.506*** (2.90)
Sheep/beef	-1.276*** (-14.43)	0.279*** (2.88)	-0.471*** (-5.37)	0.777*** (3.54)	-0.502*** (-4.90)	-1.060*** (-6.88)	0.0625 (0.66)
Deer	-1.475*** (-5.72)	-0.0348 (-0.14)	-0.832*** (-3.71)	0.139 (0.27)	-0.730*** (-2.68)	-1.136*** (-2.63)	0.474** (2.31)
Other stock	-1.314*** (-4.89)	-0.257 (-0.89)	-0.626*** (-2.63)	0.714** (1.97)	-0.262 (-1.05)	-0.355 (-1.12)	-0.273 (-1.15)
Family expectations	-0.00740 (-0.36)	0.0607*** (2.93)	0.0456** (2.38)	0.0366 (1.06)	0.0382 (1.59)	-0.0106 (-0.30)	0.0137 (0.67)
Community expectations	0.0486* (1.88)	0.0135 (0.52)	0.00132 (0.05)	-0.0570 (-1.43)	0.0446 (1.46)	0.0158 (0.35)	-0.0125 (-0.50)
Public expectations	0.00354 (0.14)	0.00921 (0.35)	0.0102 (0.41)	0.0514 (1.12)	-0.00142 (-0.05)	0.0192 (0.41)	0.0216 (0.85)
cut1	-0.444 (-1.52)	1.594*** (5.08)	-0.252 (-0.92)	2.217*** (4.20)	2.441*** (5.91)	6.111 (0.04)	1.889*** (5.60)
cut2	0.0392 (0.13)	1.751*** (5.57)	0.128 (0.47)	2.385*** (4.51)	2.556*** (6.18)	6.256 (0.04)	2.130*** (6.30)
cut3	0.626** (2.14)	1.930*** (6.13)	0.574** (2.09)	2.536*** (4.78)	2.745*** (6.62)	6.581 (0.04)	2.484*** (7.32)
Region dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1142	1142	1142	1299	1299	1299	1299

Notes: *t* statistics in parentheses. Pro-environmental management practices include plans for managing nutrients, soils and pugging. Novel farm technologies include windmills for generating electricity, computer-based management systems, automatic sensors and/or lysimeters, and lucerne and/or plantain grasses. Female, secondary schooling and below, and dairy are omitted categories. \**P* < 0.10; \*\**P* < 0.05; \*\*\**P* < 0.01.

years ago. Statistically significant positive coefficients are associated with early adoption, and statistically significant negative coefficients are associated with later adoption or no adoption. Marginal effects are reported in the Appendices S1 and S2.

Consistent with earlier findings, dairy farmers implemented plans to manage nutrients and pugging earlier than sheep and beef farmers, deer farmers and other livestock farmers ( $P < 0.01$ ), *ceteris paribus*. However, sheep and beef farmers implemented plans to manage soils earlier than dairy farmers ( $P < 0.01$ ). Sheep and beef farmers are similarly more likely to have adopted windmills for generating electricity than dairy farmers. The same is true for farmers with other types of livestock ( $P < 0.01$ ). Deer farmers are more likely to have adopted lucerne and/or plantain grasses before dairy farmers ( $P < 0.05$ ). On the other hand, dairy farmers adopted computer-based management systems and automatic sensors and/or lysimeters earlier than sheep and beef farmers and deer farmers ( $P < 0.01$ ).

Higher education is associated with earlier implementation of plans for managing soils and pugging as well as earlier adoption of computer-based management systems, automatic sensors and/or lysimeters, and lucerne and/or plantain grasses. Education does not systematically affect the timing of the implementation of nutrient management plans or adoption of windmills, at least when controlling for industry.

Expectations that the farm will be managed in an environmentally friendly way on the part of family members is associated with earlier implementation of plans to manage soils ( $P < 0.01$ ) and pugging ( $P < 0.05$ ), *ceteris paribus*, while norms in the farming community are associated with earlier implementation of nutrient management plans ( $P < 0.01$ ). Expectations from the New Zealand public are not statistically correlated with the timing of implementation.

Male respondents are predicted to have adopted computer-based management systems, automatic sensors and/or lysimeters, and lucerne and/or plantain grasses earlier than female respondents. Finally, in contrast to findings for the number of pro-environmental management practices implemented and the number of novel farm technologies adopted, experience is associated with earlier implementation of plans to manage soils ( $P < 0.05$ ) and plans to manage pugging ( $P < 0.01$ ) and with earlier adoption of lucerne and/or plantain grass ( $P < 0.05$ ). Experience is also associated with later adoption of windmills for electricity generation ( $P < 0.10$ ).

Taken together with our previous results on the number of pro-environmental management practices and novel farm technologies, innovativeness is particularly marked by dairying, higher education levels and stronger environmental norms within the family. Experience affects the timing of adoption but not the number of practices implemented or technologies adopted. Male respondents are more likely to adopt novel farm technologies.



**Table 4** Negative binomial estimates of network size

1 desirable practice	0.0611 (0.40)	—
2 desirable practices	0.284*** (4.07)	—
3 desirable practices	0.202*** (3.95)	—
1 novel technology	—	0.399*** (3.63)
2 novel farm technologies	—	0.423*** (5.21)
3 novel farm technologies	—	0.419*** (3.68)
Male	−0.0278 (−0.24)	−0.110 (−0.96)
Experience	0.000476 (0.13)	0.00444 (1.34)
Certificate	0.154 (1.05)	0.0881 (0.60)
Diploma	0.285* (1.88)	0.153 (1.10)
Bachelor's/postgraduate	0.232* (1.76)	0.204 (1.62)
Master's or above	0.626* (1.69)	0.439 (1.31)
Sheep/beef	−0.0944 (−0.75)	−0.228* (−1.92)
Deer	0.288 (0.78)	0.197 (0.53)
Other stock	−0.300 (−0.96)	−0.672*** (−2.83)
Constant	1.306*** (4.59)	1.590*** (5.86)
Region dummies	Yes	Yes
Observations	1181	1181
Chi-square test for $\alpha = 0$ ( $P$ -value)	0.000	0.000

Notes:  $z$  statistics in parentheses.

Pro-environmental management practices include plans for managing nutrients, soils and pugging. Novel farm technologies include windmills for generating electricity, computer-based management systems, automatic sensors and/or lysimeters, and lucerne and/or plantain grasses. 0 pro-environmental management practices, 0 novel farm technologies, female, secondary schooling and below and dairy are omitted categories.

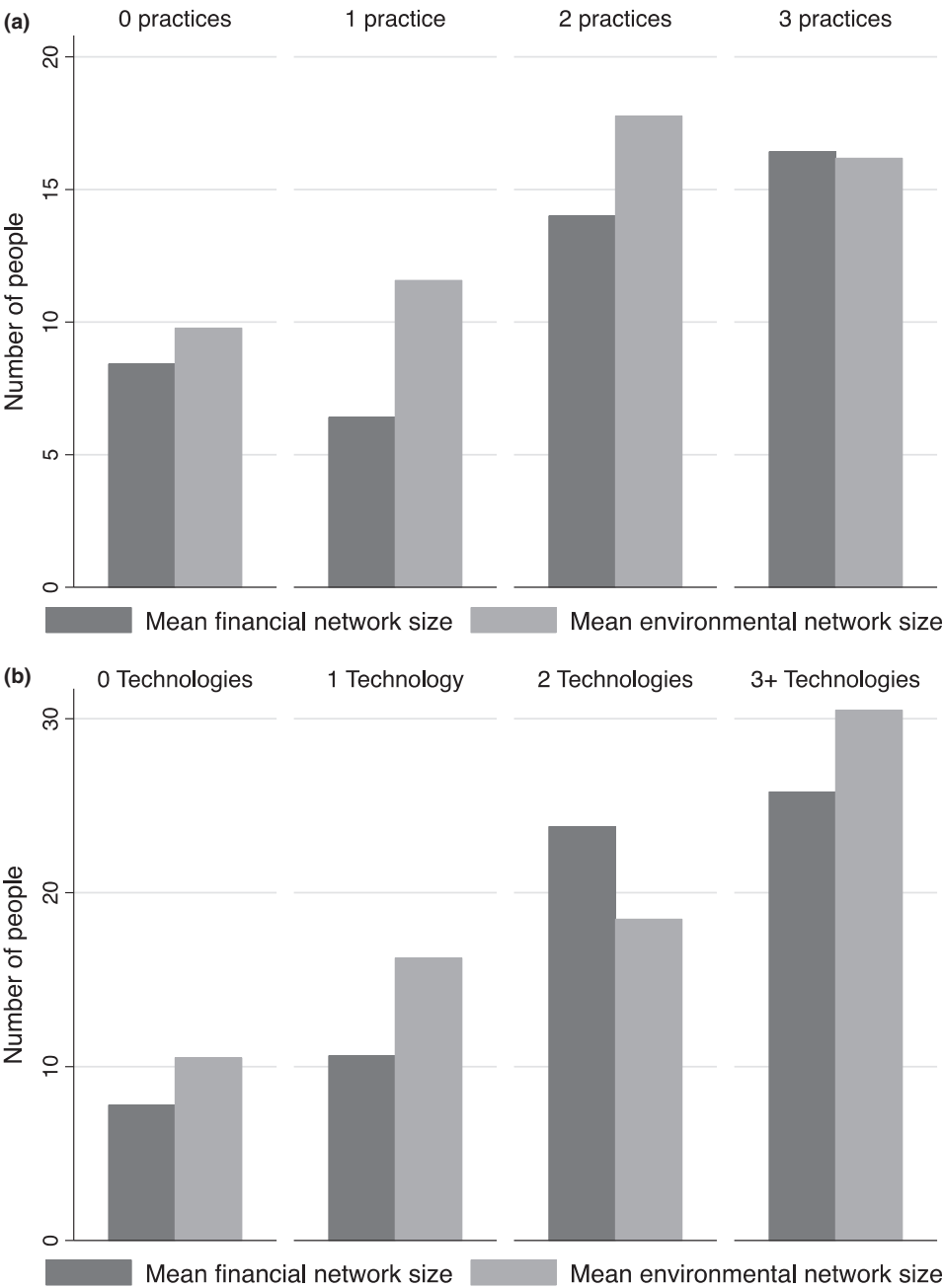
\* $P < 0.10$ ; \*\* $P < 0.05$ ; \*\*\* $P < 0.01$ .

### 3.3 Connectedness

As described above, livestock farmers who have adopted three or more novel farm technologies may be classified as being innovators (in the sense of Rogers 2003) while those who have adopted two novel farm technologies are classified as being early adopters. Similarly, those who have implemented all three pro-environmental management practices may be classified as being either innovators and those who have implemented two are considered early adopters. The remaining sample is comprised of the late majority adopters (one novel technology or one pro-environmental management practices) and laggards (zero novel farm technologies or zero pro-environmental management practices).

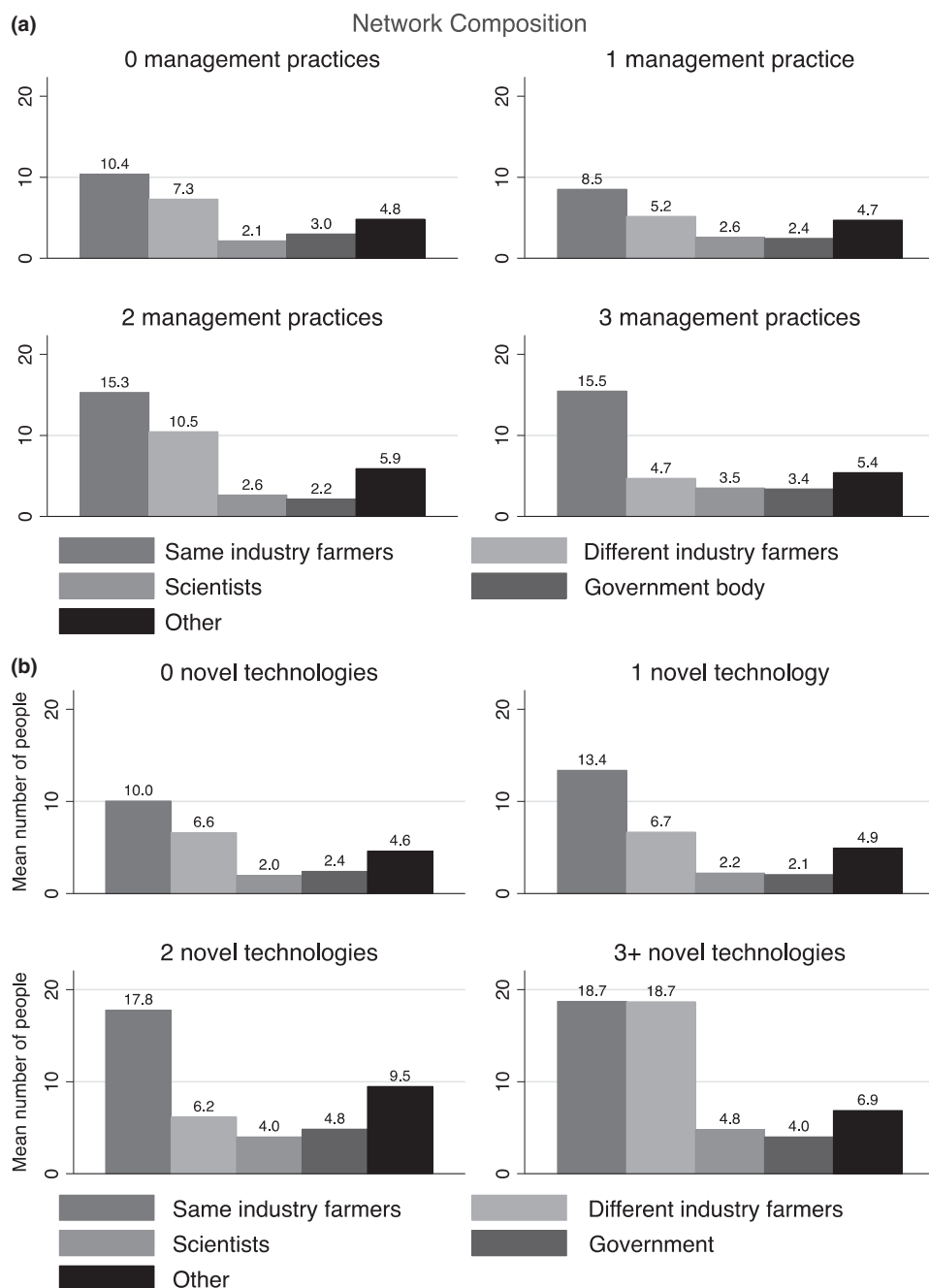
Table 4 reports estimates of network size using a negative binomial count model.<sup>6</sup> Respondents were asked either about the number of individuals with whom they discussed farm finances or environmental performance of the farm, and results are disaggregated by network type, and responses are aggregated. Whether focusing on pro-environmental management practices or novel farm technologies, innovators and early adopters each have larger professional networks than laggards ( $P < 0.01$ ). In the case of pro-

<sup>6</sup> BIC, AIC and long-run chi-squared tests all indicate that the negative binomial regression is preferred to the Poisson count model. The model is interpreted analogously as the Poisson model.



**Figure 1** Mean network size by number of pro-environmental management practices adopted (a) and number of novel farm technologies adopted (b).

environmental management practices, innovators and early adopters also have statistically larger networks than the late majority ( $P < 0.10$ ). However, we cannot distinguish network sizes of innovators from those of early



**Figure 2** Composition of networks by number of pro-environmental management practices implemented (a) and number of novel farm technologies adopted (b).

adopters statistically.<sup>7</sup> These patterns hold when the data are winsorised to remove potentially spurious outliers, for example, farmers who report discussing environmental performance with 100 others in the previous year.

These results are also presented descriptively: Figure 1 presents the average network size by the number of pro-environmental management practices (Panel a) that have been implemented and the number of novel farm technologies (Panel b) that have been adopted. Here, responses are disaggregated by network type.

This figure shows positive trends between the number of pro-environmental management practices that have been implemented and the sizes of both financial and environmental networks. For example, each additional management practice is associated with three additional contacts in financial networks and two additional contacts in environmental networks. Similarly, each additional novel technology is associated with five additional contacts in either network.

Rogers (2003) suggests that innovators have smaller networks than the rest of the public, on average, and Bandiera and Rasul (2006) show an inverse-U-shaped relationship between the adoption of new crops and network size in their sample of farmers in Mozambique. Our findings for New Zealand contradict both of these earlier studies, but are aligned with Wossen *et al.* (2013), who show that adoption rates increase with social network size.

Rogers (2003) also posits that the composition of innovators' networks is more diverse than the networks of others. We test this hypothesis by comparing the composition of networks by the number of pro-environmental management practices (Figure 2, Panel a) that have been implemented and the number of novel farm technologies (Figure 2, Panel b) that have been adopted.

The networks of innovators as defined by the number of pro-environmental management practices implemented include statistically more representatives of government than those of noninnovators ( $P < 0.10$ ). Instead using the number of novel farm technologies as a definition, innovators have larger networks of farmers in different industries ( $P < 0.01$ ) and scientists ( $P < 0.05$ ) than noninnovators. Innovators and early adopters together have more farmers from the same industry in their networks ( $P < 0.01$ ) when defined by pro-environmental management practices and more farmers from the same industry ( $P < 0.01$ ), more scientists ( $P < 0.01$ ), more government representatives ( $P < 0.05$ ) and more representatives of other groups ( $P < 0.01$ ) in their networks when defined by novel farm technologies. These findings provide strong evidence that more innovative farmers have more cosmopolitan professional networks, which leads to faster dissemination of information (Granovetter 1973, 2005).

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<sup>7</sup> In addition, education is positively associated with network size, and both sheep and beef farmers and other livestock farmers have smaller networks than dairy farmers, although these results are generally weak.

#### 4. Conclusions

The New Zealand government's plans to double the real value of primary industry exports between 2012 and 2025 and to increase the real value of exports from 30 per cent to 40 per cent of the share of real GDP are ambitious given the country's strict environmental laws and international commitments. For example, farmers who do not meet increasingly strict environmental standards under the RMA face significant fines. In addition, the government has set a target of reducing greenhouse gas emissions – the largest source of which is agriculture – to 30 per cent below 2005 levels by 2030.

Andreoli and Worchel (1978), Carr and Tait (1990), and Wu and Zhang (2013) argue that mutual trust between government and farmers is critical in encouraging diffusion of new practices and technologies whether to increase production or to enhance environmental sustainability, a finding that is consistent with results from the Survey of Rural Decision Makers. However, Small *et al.* (2016) find that farmers in New Zealand mistrust regional councils, who are charged with promoting economic well-being on communities as well as enforcing environmental regulations. Governments may nevertheless encourage adoption of new practices and technologies by encouraging diffusion through farmer networks in which innovative individuals trial new approaches and those with strong social networks encourage widespread uptake. That is, if well-connected farmers learn from innovative farmers and spread the word, then diffusion rates will increase.

We use multivariate regression to identify the traits of individual farmers who adopt pro-environmental management practices such as managing nutrients, managing soils and managing pugging and who adopt novel farm technologies such as windmills for generating electricity, computer-based management systems, automatic sensors and/or lysimeters, and lucerne and/or plantain grasses. Moreover, we evaluate innovativeness not only by counting the number of practices implemented and the number of technologies adopted, but also by evaluating the timing of those decisions, arguing that more innovative farmers will implement more pro-environmental practices and adopt more novel farm technologies than others and that they will do so earlier than others.

We find that dairy farmers adopt more pro-environmental management practices and novel farm technologies than their counterparts in sheep and beef farming, deer farming and farming of other livestock. One clear underlying reason for this finding is that the largest dairy cooperative in New Zealand makes compliance with the Dairy Clean Streams Accord (which specifically covers nutrient management) a condition of supply. In addition, milk solid prices reached historic highs in the year preceding the survey, so dairy farmers may have been in a strong financial position to implement new management practices and to adopt new technologies. We further find that

higher education levels and stronger environmental norms within the family are strongly associated with adoption. Male respondents are more likely to adopt novel farm technologies, and those with greater farming experience are more likely to adopt pro-environmental management practices. In contrast, environmental expectations of the farming community and the New Zealand public are not strongly associated with adoption.

In addition, we find that innovators and early adopters have larger networks than other farmers, including networks in which farm finances are discussed as well as those in which environmental performance is discussed. This result supports Wossen *et al.* (2013), but differs from Rogers (2003) and Bandiera and Rasul (2006), who suggest that innovators have comparatively small networks. At the same time, we find that innovators have more cosmopolitan networks than other New Zealand farmers, including more individuals from the scientific and government communities.

These findings imply that innovative farmers in New Zealand may also act as connectors to link other farmers to new ideas. This is a promising result for policy as combining the roles of innovator and connector increases the efficiency of diffusing new practices and technologies.

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### Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Appendix S1.** Marginal effects.

**Appendix S2.** 2015 Survey of Rural Decision Makers Questionnaire.