How stable are Australian farmers' climate change risk perceptions? New evidence of the feedback loop between risk perceptions and behaviour

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Abstract

The exact relationship between people's climate change attitudes and behaviour is a topic that engages policy-makers and researchers worldwide. Do climate change attitudes influence behaviour or is it possible that behaviour can change attitudes? This study uses a unique repeated survey dataset of 275 farmers (irrigators) in the southern Murray-Darling Basin from 2010-11 to 2015-16, to explore the dynamic relationship between climate change attitudes and farm adaptation behaviour. Farmers who had an increased risk exposure (expressed through higher debt, larger irrigated areas, greater share of permanent crops, and located in areas with higher temperatures and less rainfall) were more likely to agree climate change posed a risk. Whilst farmers became more accepting towards climate change over the time-period, a significant percentage of these attitudes were unstable. We suggest one reason for this instability is due to the presence of reverse causality (a feedback loop) between attitudes and behaviour. Namely, new evidence was found that farmers who agreed climate change was a risk in 2010-11, were more likely to undertake farm decisions to reduce that risk (e.g. changing crop mix, reducing irrigated area and consequently selling water entitlements) – which had the impact of negatively feeding back and reducing their stated climate change concerns in 2015-16. Conversely, farmers who were originally deniers were more likely to undertake somewhat riskier farm-production decisions (e.g. increasing water utilisation rates and irrigation areas) – which consequently had the impact of positively increasing their climate change risk perceptions in 2015-16.

Keywords: Irrigators; Murray-Darling Basin; climate change attitudes; climate change risk perception; endogeneity.

Introduction

Farming is both vulnerable to changes in climate and a significant source of greenhouse gas emissions, prompting increasing calls for coordinated adaptation and mitigation initiatives to help protect global resource supply chains (Coumou and Rahmstorf 2012; Garnaut 2011; Lim-Camacho et al. 2017). Given the success of such initiatives will depend on the participation of agricultural communities and individual farmers, it is crucial to understand how climate change attitudes influence farmer adaptation and mitigation behaviours (Haden et al. 2012; Arbuckle et al. 2013).

Australia has often been described as the 'front line of the battle for climate change adaptation' (Palutikof 2010, p. 219) and, indeed, Australian farmers face considerable and mounting pressures from earlier seasons, longer droughts, more erratic rainfall and higher temperatures (Garnaut 2011; Kiem and Austin 2013; Austin et al. 2020a; Wheeler et al. 2020b). However, Australian climate change policy has been roundly criticised, and many believe it has stymied action for the past decade (Burke 2016; Cheung and Davies 2017; Garnaut 2011). Some have suggested that the National Party of Australia (which traditionally has represented graziers, farmers and rural voters) has had a disproportionate impact on Australian climate policy (Cheung and Davies 2017; Crowley 2017).

Studies have consistently found that, compared to Australian farmers, the general public are much more accepting of climate change science and that climate change is occurring (Hogan et al. 2011; Wheeler et al. 2013). For example, in 2019, 77% of the Australian public accepted climate change was occurring, 12% did not and 11% were unsure (Australia Institute 2019). This contrasts with Australian farmers' attitudes; with many studies in the past decade finding only around a third of farmers accepted that climate change was happening (Hogan et al. 2011; Raymond and Spoehr 2013; Wheeler et al. 2013).

The psychological and environmental literature has long studied how environmental attitudes can influence behaviour (Fishbein and Ajzen 1975; Ajzen 1991); while more recent literature has studied how behaviour can influence attitudes (Albarracin and Wyer 2000; Nauges and Wheeler 2017) and the link between risk perceptions, a sense of control and attitudes (Lo and Chow 2015; Slovic 1987, 2000; Wilson et al. 1993). Van Raaij (1981) was one of the first to outline complex feedback loops between economic conditions, perceptions, and behaviour. Other research has pointed out that attitudes are often not the major driver of environmental behavioural change, and sometimes not even linked to behavioural change at all (Kollmuss and Agyeman 2002).

There has also been a huge increase in research that has tried to identify the characteristics that predict people's climate change attitudes (Hornsey et al. 2016; van der Linden 2014), with some of this research focussing on farmers' climate change attitudes (e.g. Hogan et al 2011; Raymond and Spoehr 2013). The fungibility of climate change attitudes, and how they change (or flux) over time has been noted in many synopses of public attitudes (e.g. Australia Institute 2019). However, tracking attitudes towards climate change over a long period of time, and attempting to explain why views have changed, is rare in the literature (indeed, we have not found any examples of this).

Within Australia, the Murray-Darling Basin (MDB) (an area of significant agricultural, environmental, recreational and indigenous importance) provides a much-cited example of an area that will need to adapt to changing rainfall and temperature patterns, as well as significant reductions in the water that has been allocated for irrigation use (Kiem and Austin 2013; Zuo et al. 2016; Wheeler et al. 2020b). The basin, which spans four states and one territory, is an area where the MDB Plan was fully legislated in 2012. This plan represents one of the largest returns to environmental water from a reduction in consumptive use. This water is sourced from willing sellers through buyback of licences and upgrading on- and off-farm infrastructure (see Grafton 2019 and Wheeler et al. 2017, 2020a for more detail). As well as being subject to considerable water and regulation policy change, the water allocated to irrigation has fluctuated widely over the past fifteen years – particularly during the Millennium drought of the 2000s. There is ongoing controversy over the impact that climate change will have on irrigators' water allocations, the environment, agricultural production and future viability of the irrigation industry (Wheeler et al. 2017, 2020a). Irrigators most exposed include those relying on permanent crops and larger shares of irrigation, and those utilising higher percentages of the water allocated to them, and many of them have had to adapt to both lower rainfall and lower water allocations in the past couple of decades (Grafton 2019). Increased uncertainty and stressful conditions have increased the level of distress among the general and rural population, as evidenced from a set of studies conducted recently in non-metropolitan New South Wales (Austin et al. 2018, 2020a, 2020b).

We created a panel dataset (i.e. repeated observations from the same respondents) from two surveys of the same MDB irrigators in 2010-11 and 2015-16, to try to understand how and why farmers' climate change risk perceptions have changed over time, and if there is a feedback loop between attitudes and behaviour. More precisely, the evidence for this feedback loop is established by investigating the following three questions:

<u>Question 1</u>*: Can we characterise farmers who, in 2010-11, agreed that climate change posed a risk to their region, versus those who did not perceive a climate change risk or were not sure?*

<u>Question 2</u>*: Have farmers' climate change risk perceptions evolved over time? Did farmers, who did not perceive a climate change risk in 2010-11, agree that climate change was a risk in 2015-16, and/or vice versa?*

<u>Question 3</u>*: Are farmers' climate change risk perceptions associated with major farm production decisions made on the farm between the two surveys? Can we detect a feedback relationship between risk perceptions and behaviour?*

We hypothesise that there may be a feedback loop between climate change risk perceptions and farmer behaviour, in the sense that actions undertaken by farmers between the two surveys may have altered their exposure to risk and hence their perception of the risk posed by climate change. We focus specifically on major production decisions which included buying and selling of land and water entitlements, increasing or decreasing irrigated area, changing crop mix, improving irrigation infrastructure, and utilising solar and battery technology for irrigation water pumping.

Literature Review of Farmers' Climate Change Attitudes

Farmers' stated attitudes towards climate change were often influenced by how the questions were asked. For example, farmers were more likely to agree with the statements that the climate is changing (or occurring) than they were in regards to statements that climate change is caused by human activity (Raymond and Spoehr 2013). In an early study among farmers in the US, Diggs (1991) revealed that 30-41% of farmers (n=432) agreed with the question 'is the climate changing'. This proportion has steadily increased over time; with later US studies generally finding between half and two-thirds of American farmers agreeing that climate change is now occurring (Safi et al. 2012; Arbuckle et al. 2013, 2015; Niles et al. 2013; Campbell et al. 2019). Elsewhere, it has also been found that: 55% of Danish farmers (n=1053) in 2014 agreed that global change was occurring (Woods et al. 2017); 70% of Chinese farmers (n=1133) agreed climate change posed a risk to their livelihoods (Zhai et al. 2018); two-thirds of Iranian farmers (n=350) stated global warming is taking place (Azadi et al. 2019); 48% of Scottish farmers (n=550) agreed that average annual temperatures will increase in the future (Barnes et al. 2013); and just over half of New Zealand farmers (n=490) agreed that the global climate was changing (Niles and Mueller 2016). In particular, Niles and Mueller (2016) investigated how the presence of irrigation infrastructure was associated with climate change perceptions, and found evidence to suggest that the presence of infrastructure potentially positively influenced perceptions that annual rainfall had increased over time. Within Australia, Hogan et al. (2011; Table 11) reported that belief in climate change varied from 27-42% across different types of farmers (comfortable non-adaptors, cash poor longer-term adaptors and transitioners, as identified by cluster analysis using twenty climate change-related latent variables) in 2008 (n=3993). A small survey of Victorian farmers (n=90) found that 70% believed that the climate is indeed changing (Rogers et al. 2012); while Wheeler et al. (2013) provide the only specific survey of irrigators (that we know of) – they found that 32% of MDB irrigators in 2010-11 (n=946) believed climate change posed a risk for their region.

Farmer views regarding the main causes of climate change (e.g. human versus non-human induced) were more divergent than the presence of climate change itself. Farmers were less likely to believe that climate change is human induced (e.g. see US studies by Arbuckle et al. 2013; Campbell et al. 2019; Rejesus et al. 2013; Safi et al. 2012). Within the Australasia region, a survey of 292 farmers in South Australia by Raymond and Spoehr (2013) found that 39% agreed that human-induced climate change existed. Rogers et al. (2012) found 68% of Victorian farmers agreed that human activity was influencing climate change, and Niles and Mueller (2016) also found the majority of New Zealand farmers agreed. In a study of 823 rural residents in New South Wales, Austin et al. (2020a) highlighted that major concerns about climate change related to: i) suffering under climate change; ii) causes of climate change; iii) extremes of climate change; and iv) leadership and action to address climate change.

In terms of understanding the socio-demographic characteristics associated with farmers' climate change attitudes, a range of studies have found that female farmers are more likely to acknowledge the existence of climate change and hold more scientifically accurate knowledge (Smith et al. 2014; Hamilton et al. 2015; Zamasiya et al. 2017). Similarly, higher education levels among farmers were found to be associated with believing in climate change, recognising the role of human activity within climate change, and the perception of climate change risks (Barnes et al. 2013; Raymond and Spoehr 2013; Wheeler et al. 2013; Hamilton et al. 2015). Wheeler et al. (2013) and Hamilton et al. (2015) found that lower farmer age was significantly associated with believing in climate change, while Rejesus et al. (2013) found the opposite result. As discussed above, localised effects of climate change were found to be a major influence on farmer attitudes, with Mase et al. (2017) highlighting a significant positive correlation between a farmer noticing more variable weather and belief in anthropogenic climate change. Further results from California (Niles et al. 2013), China (Shi et al. 2019) and Nigeria (Ayanlade et al. 2017) also indicate the large majority of farmers recognised fundamental changes in climatic conditions.

Other notable positive influences on climate change attitudes included a farmer having: a successor (Barnes et al. 2013; Wheeler et al. 2013); higher on-farm income (Raymond and Spoehr 2013); off-farm employment (Rejesus et al. 2013); higher concern about future impacts (Arbuckle et al. 2013; Niles and Mueller 2016); and democratic political affiliation (Smith et al. 2014). In terms of water availability, Haden et al. (2012) found that perceived changes in water availability had significant effects on Californian farmer intentions to adopt climate change mitigation and adaptation strategies. Furthermore, Wheeler et al. (2013) found that Australian farmers' acceptance of climate change risk was statistically significantly associated with having received fewer water allocations – during both the current season and over the previous five years. Finally, and returning to the prominence of agriculture within the landscape of climate change, Hogan et al. (2011) concluded that an ability to cope with change, social connectedness and readiness to use information constructively, all positively influenced farmer interest in (and capacity to adapt to) climate change.

Risk perceptions and climate change

There has been an increasing focus in the climate change attitudinal literature on the relationship between a sense of control and climate change concerns. Slovic (1987, 2000) first proposed that individuals' risk perceptions are affected by their ability to control such risks, and this ability was highly associated with their financial resources. Indeed, a sense of control has been found associated with both country and individual household wealth (Lo and Chow 2015), and that wealth and income determine the level of risk people are willing to take (Lo 2016). Higher income and resources could lead to an increased sense of control about the world and future outcomes, a reduced sense of personal vulnerability and, therefore, reduced concern about climate change issues. In a study of households across eleven OECD countries on the relationship between climate change concerns and water and energy mitigation behaviour, Nauges and Wheeler (2017) found that while it was true that climate change attitudes positively influenced specific household mitigation actions, the relationship was more complex in the sense that adoption of mitigation behaviour negatively fed back on households' climate change concerns. This effect was more likely to occur in 'environmentally-motivated' households, and for mitigation behaviour that was high cost and lower diagnostic in nature (e.g. putting solar panels on the house, rather than actions such as turning off lights more often). In addition, Wheeler et al. (2013) found that farmers in the MDB who agreed climate change posed a risk to their region were not planning to expand their farm, but they were planning to change their crop mix; adopt new efficient irrigation infrastructure; decrease their irrigated area; and buy more water entitlements (albeit these last two actions were insignificant). Reverse causality (a feedback loop) between attitude and behaviour was found for farm actions that involved implementing strategies to deal with current or future water shortages (changing crop mixes, adopting more efficient infrastructure, selling land and decreasing irrigated area). Reverse causality was not found for the impact of climate change perceptions on other types of farm behaviour (e.g. such as selling water entitlements, buying farm-land or increasing irrigation area). Such results suggest the flexible nature between risk perceptions and adaptation behaviour. This study only looked at future farm adaptation at one point in time, it did not study the relationship between actual implemented farm actions and climate change beliefs, nor how beliefs or farm behaviour changed over time. Nauges and Wheeler (2017) recommended that additional experiments, or panel datasets that follow people's concerns and behaviour over time, would be needed to explore this relationship further and to investigate in particular the presence of a lag between experiencing concern and implementing mitigation behaviour, and vice versa.

Hence, of key interest to this study is the relationship between farm action and climate change beliefs, and how attitudes can change over time, depending upon both a) personal and local environment conditions; and b) farm actions undertaken within the time-period. To date, the literature has focussed on cross-sectional (e.g. one year) snapshots of farmers' (and public) attitudes at particular points in time, and the associations of those beliefs with a set of locational, farm and socio-demographics. Wilson et al. (1993) discussed a possible feedback phenomenon between behaviour (actions) and perceptions in a study of US dairy farmers' risk perception and management tools. Along the lines of van Raaij (1981)'s framework showing complex feedback loops between economic conditions, perceptions, and behaviour, Wilson et al. (1993) argued that farmers' actions undertaken to manage risk in the past, by altering the sources of variability, may have changed their current perception of risk. However, this assertion could not be formally tested since the dairy farmers were surveyed only once. Austin et al. (2020b) explained the variability of New South Wales rural residents' attitudes to drought by the possibility 'that people have started to adapt (e.g. changes to household budget, farming practices or lifestyle) to drought or that government funding has become available' (Austin et al. 2020b: 14). Niles and Mueller (2016) have provided one indication of how a sense of control in agriculture (namely the presence of irrigation infrastructure) was associated with farmers' views that annual rainfall had increased over time; while Wheeler et al. (2013) and Nauges and Wheeler (2017) provided evidence of some reverse causality between climate change risk perceptions and behaviour. This study seeks to extend the literature by investigating the same farmers' climate change attitudes and behaviour over a period of five years, using a unique survey dataset, during which 275 Australian farmers were surveyed twice (2010-11 and 2015-16).

Data and Case Study Area

The empirical analysis that follows combines data from two telephone surveys of irrigators living in three states of the southern Murray Darling Basin (MDB): New South Wales (NSW), South Australia (SA) and Victoria (VIC). The three regions cover various industries: annual crops such as rice and cereal in NSW (Murray and Murrumbidgee River regions); livestock production and dairy in VIC (Goulburn–Murray Irrigation District and Murray River regions); and perennial crops such as citrus, wine grapes, fruit and nuts in SA (Riverland). The first telephone survey was conducted in 2010-11 (n=946); and the second was conducted in 2015-16 (n=1000).[1] The surveys were randomly sampled from a given irrigator population and are regarded as representative. For example, average age, industry and farm size are similar to ABS (Australian Bureau of Statistics) and ABARES (Australian Bureau of Agricultural and Resource Economics and Sciences) irrigation farm surveys (Zuo et al. 2016). Information was collected on farmland; irrigation infrastructure; intentions and plans for the past five years and next five years; socio-demographic characteristics; climate change risk perceptions; and a range of values and attitudes. Our focus is on farmers' perception of climate-related risk, which we measure through their answer to the following question: "Do you believe that climate change poses a risk to your region?" Possible answers were: i) no, ii) yes, iii) unsure, or iv) don't know. From now on we combine the "unsure" and "do not know" together under

[1] Irrigators were randomly sampled from irrigator organisations and commercial farming lists. The first survey had a total response rate of 30% (or 37% which included those who agreed to be surveyed at a later date, but were not called back given sample sizes were reached); while the second survey had a response rate of 51% (or 73% including call-backs).

an "unsure" label. The term "climate change" was not specifically defined to the survey participants so we are not able to distinguish whether farmers' risk perceptions were formed from their current knowledge about climate change in general or from their observation of changes in (local) weather patterns. The understanding of how their climate-related perceptions were built is outside the scope of this research.

In this article, we study 275 irrigators who answered both telephone surveys. Since we are primarily interested in the (possible) change in the same respondent's climate change risk perception between 2010-11 and 2015-16, it is important to check that it was the same person (and not different household members on the same farm) interviewed in both years.[2] Given that the name of the respondent was not recorded for ethical reasons, the criteria we used to establish it was the same respondent during both surveys were if the respondent's: a) gender was the same; and b) age between the two survey rounds varied between 4 and 6 years. Table A1 in the Appendix includes statistics on the key characteristics such as geographical location, farm size, farm income, respondent's age, education, gender, industry, and water ownership for the panel sample of 275 irrigators – as well as the full sample of 946 irrigators in 2010-11. The comparisons suggested that the panel sample and the full sample were not statistically significantly different in terms of these key characteristics and therefore attrition bias was unlikely.

Methods

For the descriptive statistics, the independent two sample t-test was used to compare the mean of continuous variables and proportion test for binary variables between two groups, i.e. agreed that climate change posed a risk to their region ("Yes" answer) vs. others ("No" or "Unsure" answer) and climate change risk denier ("No" answer that climate change posed a risk) vs. others ("Yes" or "Unsure" answer).

The independent t-test, assuming the variances of the two groups are equal, has a null hypothesis that the difference between the two groups is zero. Suppose Group A (e.g., believer) and Group B (others) are the two groups to compare; the t-test statistic value can be calculated as follows:

[2] For example, if we were interested in modelling a farm characteristic such as water extracted rather than a personal characteristic, a larger panel dataset would have been available (e.g. 338 farms used in Wheeler et al. 2020a).

$$t = \frac{m_A - m_B}{\sqrt{\frac{s^2}{n_A} + \frac{s^2}{n_B}}}$$

where m_A and m_B represent the means of groups A and B respectively, n_A and n_B represent the sizes of groups A and B respectively, and s^2 is an estimator of the common variance of the two samples which can be calculated as:

$$s^2 = \frac{\sum(x - m_A)^2 + \sum(x - m_B)^2}{n_A + n_B - 2}$$

For binary variables, a proportion test with a null hypothesis that the proportions of the two groups are equal is employed. Let $\widehat{P_A}$ be the observed proportion in Group A and $\hat{P}_B$ be the observed proportion in Group B. A test of the difference between the two proportions used an asymptotically normally distributed test statistic expressed as:

$$z = \frac{\widehat{P_A} - \widehat{P_B}}{\sigma}$$

where σ is the standard error of $\widehat{P_A} - \widehat{P_B}$.

In order to investigate our third research question, Probit regression models were used to model changes in irrigators' climate change risk perceptions between 2010-11 and 2015-16. Two types of changes were investigated including: 1) from 'believer' in 2010-11 to 'denier' or 'unsure' in 2015-16; and 2) from 'denier' in 2010-11 to 'believer' or 'unsure' in 2015-16.

The following equation was estimated for each of the changes:

$$\text{Change}_k^* = X\beta + \varepsilon \qquad (1)$$

where: k=1,2 respectively for change 1) and change 2), Change_k^* is a latent variable ranging from $-\infty$ to ∞, X is a vector of independent variables including major farm production decisions between 2010-11 and 2015-16 , β is a vector of parameters to be estimated and ε is a classical error term. The observed binary variable for change is 1 if $\text{Change}_k^*>0$ and 0 if $\text{Change}_k^*\leq 0$. Two distributions of ε are commonly assumed: ε is assumed to be distributed normally with Var (ε) = 1 – the binary probit model; and second, ε is assumed to be distributed logistically with Var (ε) = $\pi^2/3$ – the binary logit model.[3] Models were checked for any serious multicollinearity (i.e. no variance inflation factors above five, and absolute

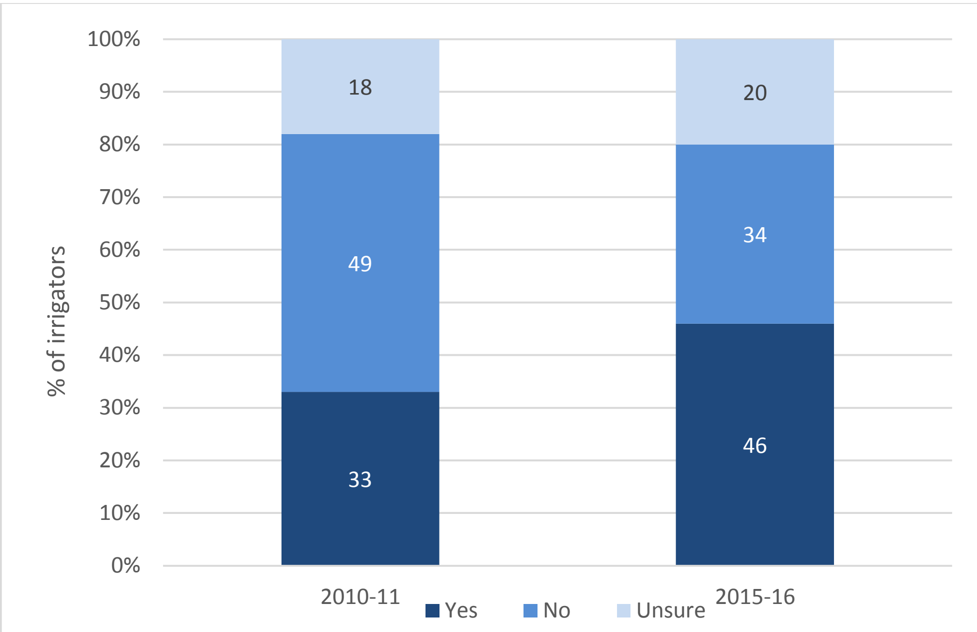
[3]The two approaches are similar in terms of comparing the marginal effects of regressors (Amemiya 1981).

correlation coefficients above 0.7), and robust standard errors were used. Independent variables in Equation (1) are defined in Table A3 in the Appendix.

Results: climate change risk perceptions

We first study the responses to the climate change risk question: "Do you believe that climate change poses a risk to your region?" Figure 1 shows the distribution of the three possible answers among the sample of farmers (n=275) across the five years. Note, Table A2 in the Appendix presented the results for the full sample of farmers and similar distributions are observed.

Figure 1. Distribution of farmers' climate change risk perceptions for their region (n=275)



The perceived risk induced by climate change has strengthened among the 275 farmers between 2010-11 and 2015-16. Over the five-year interval, the number of farmers who believed that climate change *did not* pose a risk to their region decreased from 49% (135 farmers) to 34% (94 farmers). In contrast, there was a 13% increase (from 33% to 46%) of farmers who *do* believe climate change poses a risk to their region, and a 2% increase of farmers who stated they were unsure. Such an increase in farmers' climate change risk perceptions was similar to the trend in views of the general Australian public, with 64%

agreeing that climate change was occurring in 2012, and 77% in 2019 (Australia Institute 2019).

Results: insights on the three main questions

Question 1: Can we characterise farmers who, in 2010-11, accepted climate change posed a risk to their region, versus those who did not perceive climate change as a risk or were not sure?

Table 1 illustrates the mean characteristics of farmers in 2010-11 across the entire sample, and for sub-groups of farmers classified based on their climate change risk perception. We distinguish between those who believed climate change posed a risk in 2010-11 (i.e. the 91 farmers who answered "Yes" to the climate change question) and those who disagreed (i.e. the 135 "No" farmers). The "Yes" group characteristics are compared to the sample remainder (namely 184 farmers) including: a) those who disagreed that climate change posed a risk (the deniers); and b) those who were unsure. The "No" group characteristics are compared to the sample remainder of 140 farmers who answered "Yes" or were unsure. Variables for which mean tests were found statistically significant at the 1, 5 or 10% level are in bold.[4]

We observed some significant differences across MDB states: in the group of deniers (last column, "No" answer in Table 1), there is a (significantly) higher representation of farmers operating in VIC and a (significantly) lower representation of farmers living in SA, compared to the rest of the sampled population. These discrepancies, in terms of climate change risk perceptions across the three states, are most likely related to the type of industry farmers are engaged in. Deniers had the lowest percentage of land planted with permanent crops (grapes or fruit trees). Indeed, in SA permanent crops dominate our panel dataset, since 79% of land was planted with either grapes or fruit trees in 2010-11 (on average over the 275 farmers); while permanent crops covered an average of 13% of the land owned by Victorian farmers and 14% in NSW.

[4] We ran a simple Probit regression on the group of 275 farmers to try and identify significant explanatory variables to explain the probability of believing climate change poses a risk in 2010-11 (the "Yes" farmers). Results confirm the outcome of our mean tests in general. We also find that those farmers who are not indebted are less likely to agree with climate change risk.

Table 1. Farmers' average characteristics and climate change risk perceptions in 2010-11

	2010-11 Full sample (n=275) Freq. (%) or mean	*2010-11 "Yes"* [a] *(n=91) Freq. (%) or mean*	*2010-11 "No"* [b] *(n=135) Freq. (%) or mean*
State: NSW	98 (36%)	34 (37%)	43 (32%)
VIC	108 (39%)	33 (36%)	**65 (48%)***
SA	69 (25%)	24 (27%)	**27 (20%)***
Education level:			
Below year 10	46 (17%)	**9 (10%)****	**31 (23%)*****
Year 10-12	140 (51%)	43 (47%)	72 (53%)
Tafe and equiv.	38 (14%)	**18 (20%)****	15 (11%)
Uni. and equiv.	51 (19%)	21 (23%)	**17 (13%)****
Male	0.90	0.87	0.91
Age (years)	55.4	54.4	56.0
Environ. group member (0/1)	0.27	0.32	0.26
Farm size (ha)	506	465	**594**[c]
Irrigated size (ha)	153	**195***	126
Irrigated land in permanent crops - grape & fruit trees (%)	30.0	35.1	**22.8*****
Irrigated broadacre land (%)	24.7	23.9	26.1
Irrigated pasture/grazing land (%)	35.1	**28.3***	**41.1****
Total volume of high entitlement water held (ML)	297	322	300
Mean end allocation previous 5 years[d]	52.2 (264 obs.)	53.8 (87 obs.)	50.5 (130 obs.)
Water utilisation rate (%)[e]	55.7	58.4	55.4
Net farm income ($1,000)	33.8 (247 obs.)	31.5 (84 obs.)	35.8 (119 obs.)
Off-farm income (% of total income)	38.9%	37.8%	40.2%
Debt to equity ratio	0.40	0.49***	0.35**
Likelihood of successor (yes=1)	0.38 (261 obs.)	**0.28**** (87 obs.)	**0.43*** (130 obs.)
Mean annual temperature (°C, 1982-2011)	23.2	23.3	**23.1****
Annual total rainfall (mm, previous year)	402	395	411*
Mean annual total rainfall (mm, 1982-2011)	365	366	368
Standard dev. annual temp. (°C, 1982-2011)	0.69	0.70	0.69
Standard dev. of annual rainfall (mm, 1982-2011)	110	111	111
Mean annual rainfall percentile (2006-2011)	36.3	36.1	36.1

Notes: [a] *, **, *** indicate statistical significance from the two-sample t-test for equal means (at the 10, 5 and 1% level, respectively) of the difference between the mean of the variable for 2010-11 believers ("Yes" column) and the mean for the rest of the farmers. No indication indicates "non-statistically significant".
[b] *, **, *** indicate significance (at the 10, 5 and 1% level, respectively) of the difference between the mean for 2010-11 deniers ("No" column) and the mean for the rest of the farmers. No indication indicates "non-statistically significant".
[c] significant at the 11% level.
[d] weighted by security ownership.
[e] Defined as the water extracted by irrigators as a percentage of the water allocated/received for a given year, taking into account entitlement reliability. It can be significantly influenced by using much larger volumes through purchased water, than water received from entitlements owned. Hence, water utilisation rates were capped to 100%, indicating these irrigators used 100% of their own water entitlements.

Conversely, deniers had a higher percentage of land in pasture and grazing compared to the believer group. Farmers who have engaged primarily in permanent cropping are significantly less represented in the denier group, therefore are more likely to agree climate change poses a risk. It is known that farmers having permanent crops are more exposed to the risk of drought, since these crops have to be irrigated for the trees (and the investment) to be preserved over future years (Wheeler et al. 2020a). The risk faced by farmers planting annual crops is not as pressing in the sense that a major drought would only affect production in the current year/s – and farmers also usually have the choice between growing an annual crop each year or not (Nauges et al. 2016).

In line with attitudes found among the general population and other farming surveys, we observe that farmers with lower education are more likely to be in the denier group (Barnes et al. 2013; Wheeler et al. 2013; Hamilton et al. 2015, Nauges and Wheeler 2017). The average mean temperature over the last 30 years was found to be significantly (p-value<0.05) lower among deniers locations (albeit the difference between means very small), and total rainfall in the previous year – which is found significantly (p-value<0.10) higher among deniers farm locations. This supports literature (e.g. Mase et al. 2017) that suggests local environmental conditions play a part in influencing climate change risk perceptions.

There is an almost statistically significant difference in average farm size (at the 11% level) for those farmers who did not believe climate change posed a risk in 2010-11. Farm size was larger on average for deniers than in the rest of the sampled population, which may again be linked to the type of industry farmers are engaged in. However, believers had a significantly statistically larger irrigated area than all other farmers. While there was no statistically significant difference in net farm income, water utilisation rate or off-farm income for either believers or deniers, believers had statistically significantly higher debt to equity ratios – while deniers had statistically significantly lower debt to equity ratios. Finally, we observed that there are a significantly higher proportion of farms with an identified successor among the denier group. This is not really surprising since deniers, due to their perception that climate change is not posing a risk, most likely have more positive expectations about the future than farmers who are believers.

Other than education, irrigators' climate change risk perceptions seem to be driven by their capital exposure to the risk of drought, as well as their capacity to mitigate any consequences in terms of debt to equity levels. Those having a larger share of their land planted with grapes or fruit trees – hence being more exposed to the risk of crop failure (and more exposed to the risk of losing a long-lived asset) – are more likely to believe climate change is posing a risk.

Question 2: Have farmers' climate change risk perceptions evolved over time? Did farmers, who did not perceive climate change risk for their region in 2010-11, perceive it as a risk in 2015-16, and vice versa?

Table 2 describes the evolution in risk perceptions between 2010-11 and 2015-16.

Table 2. Matrix of farmers' climate change risk perceptions across time (n=275)

		2015-16			
		No	***Yes***	***Unsure***	***Total***
2010-11	***No***	71	36	28	135
		53%	27%	20%	100%
	Yes	13	71	7	91
		14%	78%	8%	100%
	Unsure	10	20	19	49
		20%	41%	39%	100%
	Total	94	127	54	275
		34%	46%	20%	100%

Among the 275 farmers, 161 (59% of the sample) perceived risk in a similar manner in 2010-11 and in 2015-16. A total of 71 farmers in Table 2 (26% of the sample) believed climate change would not pose a risk to their region in 2010-11 and kept the same opinion in 2015-16 ("No"- 2010-11 and "No"- 2015-16). The same number of farmers (71, or 26% of the sample) believed in 2010-11, and still believed in 2015-16, that climate change posed a risk to the region ("Yes"- 2010-11 and "Yes"- 2015-16). Only 19 farmers (7%) declared being unsure in both years.

We are primarily interested in the 118 farmers (43% of the sample) whose perceptions about climate change risk changed over the five-year interval: these include 36 respondents who, initially, did not believe climate change posed a risk for their region but, five years later, changed their mind and stated the opposite. Among the deniers in 2010-11, another 28 became unsure in 2015-16. Interestingly we also observe that 20 farmers, who believed climate change posed a risk in 2010-11, changed their minds in 2015-16 by answering "No" or "unsure" in 2015-16.

Table 3 classified farmers who had changed their minds about climate change risk into two groups: 1) 20 farmers who originally perceived climate change posed a risk in 2010-11 and then changed their mind in 2015-16 (either to denial or unsure); and 2) 64 farmers who believed climate change did not pose any risk in 2010-11 and then changed their mind in 2015-16 (hence answering "Yes" or "Unsure"). In each column we report the variable mean of either group 1 or 2 and the variable mean for the rest of the farmers inside parentheses.

Group 1, which includes the 20 farmers (versus the rest) who believed climate change posed a risk in 2010-11 and no longer believed this in 2015-16, has a significantly lower proportion of males and a significantly lower net farm income than the rest of the population. Group 2, which includes the 64 farmers (versus the rest) who perceived climate change a greater risk after the 5-year interval (from denier to believer or unsure), has more of the low-educated farmers than the rest of the population. Farmers in Group 2 also recorded a higher net farm income and a lower share of land in permanent crops (both measured in 2010-11) than the rest of the population. Finally, farmers in Group 2 experienced a much larger decline in rainfall in the previous year than the rest, which may contribute to the switch from denier in 2010-11 to believer in 2015-16. While acknowledging the relatively small sample size, this suggests that – although climate change is a long-term concept – farmers may link it to short-term climatic fluctuations over the period of just a few years.

In the following section, we seek to better understand the characteristics identified in Table 3, by considering why risk perceptions may have changed after farmers modified their exposure to risk by undertaking long-term/investment decisions – implying significant structural changes on the farm.

Table 3. Profile of farmers depending on the change in their climate change risk perception

	Group One – Believer that climate change posed a risk in 2010-11 to Otherwise in 2015-16[a]	*Group Two – Denier that climate change posed a risk in 2010-11 to Otherwise in 2015-16*[b]
Male	**0.75 (0.91)****	0.89 (0.90)
Age (years) in 2010-11	54.6 (55.5)	54.5 (55.7)
Low education in 2010-11[c]	0.65 (0.68)	**0.75 (0.65)**[e]
Env group membership in 2010-11	0.30 (0.26)	0.30 (0.26)
Farm size (ha) in 2010-11	287 (523)	608 (475)
Net farm income (AU$ 1,000) in 2010-11	**21.0 (35.0)****	**40.2 (32.0)***
Land in permanent crops in 2010-11 (1 if permanent cropping is present on the farm; 0 otherwise)	40.0% (29.2%)	**20.3% (33.0%)****
Likelihood of successor in 2010-11	0.32 (0.38)	0.42 (0.36)
Total volume of high entitlement water held in 2010-11 (ML)	381 (290)	286 (300)
Mean end allocation previous 5 years in 2010-11[d] (%)	54.8 (52.0)	50.0 (52.9)
Water utilisation rate in 2010-11 (%)	55.9 (55.7)	55.5 (55.8)
Difference between rainfall (mm) in 2014-15 and rainfall in 2009-10	-147 (-142)	**-163 (-136.0)*****
Long term rainfall percentile of previous five years in 2015-16	56.3 (55.2)	**54.3 (55.6)****
# of farmers	20 (compared to the other 255 farmers in brackets)	64 (compared to the other 211 farmers in brackets)

Notes: [a] *, **, *** indicate statistical significance (at the 10, 5 and 1% level, respectively) from the two-sample t-test for equal means of the variable for farmers in Group 1 and the mean for the rest of the farmers. No indication indicates "non-statistically significant". [b] *, **, *** indicate statistical significance (at the 10, 5 and 1% level, respectively) from the two-sample t-test for equal means of the variable for farmers in Group 2 and the mean for the rest of the farmers. No indication indicates "non-statistically significant". [c] Dummy variable that takes the value 1 if farmer's education level is year 12 maximum, and 0 otherwise. [d] Weighted by security ownership. [e] Mean difference is significant at the 15% level of significance.

Question 3: Are farmers' climate change risk perceptions associated with major farm production decisions made on the farm between the two surveys? Can we detect a feedback relationship between perceptions and behaviour?

As has been found previously in the literature (e.g. Nauges and Wheeler 2017), we hypothesise climate change risk perception could be endogenous and subject to a feedback loop, in the sense that actions undertaken by farmers between the two survey periods may have altered their exposure to risk and hence their perception of the risk posed by climate change. Taking farmers' original climate change belief as a base, we compared farmers' significant production decisions made between 2010-11 and 2015-16. We focussed on farm major production choices (all binary variables), and also the change in total irrigated area (continuous decision expressed in percentage terms).

Farmers who agreed climate change posed a risk to their region in 2010-11 were more likely to sell land between 2010-11 and 2015-16 (18% of believers versus 8% of deniers/unsure). Believers, as at 2010-11, were also more likely to sell water entitlements between 2010-11 and 2015-16 (40% of believers versus 29% for deniers/unsure). The difference was statistically significant at the 10% level. On the contrary, those who did not perceive climate change as a risk in 2010-11 were more likely to buy water entitlements over the next five years (probability of 20% for deniers versus 12% for believers/unsure, with the difference statistically significant at the 10% level). In line with the purchase of water entitlements, we observed that deniers in 2010-11 increased their irrigated area significantly more than believers/unsure (this is reflected in the variable that measures the change in irrigated area).

Figures in Table 4 suggest two categories of farmers may coexist: the first category being believers in 2010-11 who decided to disinvest by selling land and water entitlements. These farmers presumably saw (irrigation) farming as a risky activity, and we know they considered climate change a risk factor. They reduced their risk exposure by lowering the scale of their farming activities and hence their irrigation farming dependence. We do not see any statistically significant evidence that these farmers planned to exit and sell the farm (although believers were relatively more likely to have said they were thinking of leaving the farm in 2010-11). It must be noted that our panel dataset includes everyone who continued farming, so this is not the best test for farm exit.

Table 4. Relationship between climate change risk perceptions in 2010-11 and major production decisions over the next five years

Between 2010-11 and 2015-16, irrigators' major production actions:	*2010-11 Strong believer ("Yes only")*	*2010-11 "No" or "Unsure"*	*Mean test p-value*	*2010-11 Strong denier ("No only")*	*2010-11 "Yes" or "Unsure"*	*Mean test p-value*
Sold farm-land (0/1)	0.18	0.08	**	0.08	0.14	*n.s.*
Bought farm-land (0/1)	0.20	0.22	*n.s.*	0.22	0.21	*n.s.*
Sold water entitlements (0/1)	0.40	0.29	*	0.30	0.34	*n.s.*
Bought water entitlements (0/1)	0.14	0.17	*n.s.*	0.20	0.12	*
Increased irrigated area (0/1)	0.23	0.19	*n.s.*	0.24	0.19	*n.s*
Decreased irrigated area (0/1)	0.34	0.22	**	0.25	0.26	*n.s*
Change in irrigated area (%)[a]	31	280	*n.s.*	348	57	**
Improved irrigation efficiency (0/1)	0.79	0.81	*n.s.*	0.81	0.79	*n.s.*
Changed crop mix (0/1)	0.53	0.53	*n.s.*	0.53	0.52	*n.s.*
Utilised solar and battery technology (0/1)	0.36	0.28	*n.s*	0.31	0.30	*n.s*
Change in water utilisation rate	16.50	22.71	*n.s.*	25.85	15.65	**
Climate Change Actions (e.g. tree planting; soil management; timing changes; canopy/shed for plant/shelter) (0/1)	0.07	0.07	*n.s.*	0.06	0.07	*n.s.*
# of farmers (275 in total)	91	184		135	140	

Notes: [a] Computed as (irrigated area in 2015-16 take irrigated area in 2010-11)/irrigated area in 2010-11. The change can be either negative or positive. There were 21 farms that had zero irrigated area in 2010-11 but positive irrigated area in 2015-16. Hence their percentage change in irrigated area was not defined and they are not included in the calculation of the variable named "change in irrigated area".

The second group includes deniers in 2010-11. In the following five years, deniers increased their farm-irrigated area and purchased more water entitlements. It seems these farmers hoped to continue farming in the future, but wanted to be better protected against drought risk through increased water entitlements. This may illustrate water entitlement trade is partly driven by differences in risk perception and risk management strategies (as suggested in Nauges et al. 2016). Group 1 farmers (the believers) disinvest in farming and send water entitlements to the second group of farmers (the deniers) who aim to continue farming activities, albeit with reinforced protection against drought.

Finally, we test our feedback hypothesis: namely that changes in climate change perceptions from 2010-11 to 2015-16 could have been driven, among other factors, by major farm decisions undertaken during this time-period, in particular production decisions including: buying and selling of land and water entitlements; increasing or decreasing irrigated area; changing crop mix; improving irrigation infrastructure; tree planting; soil management; changing timing of practices, and utilising solar and battery technology for irrigation water pumping.[5] We used the two groups of farmers to test the research questions.The main hypothesis tested was that farmers who were (or were not) originally concerned about climate change risk may have changed their mind after undertaking various production decisions that decreased (or increased) their exposure to climate change risk. We hypothesise that selling land, decreasing irrigated area and consequently selling water entitlements, decreasing water use percentage, changing crop mix, and utilising solar and battery technology leads to a reduced risk exposure. Reducing risk increases farmers' sense of 'control' and hence decreases the likelihood that they perceive climate change as a risk. Conversely, farm actions such as purchasing land, increasing irrigated area and consequently increasing water entitlements, increases risk exposure and hence the likelihood that climate change is perceived as a risk. If there is evidence for the above two hypotheses, it would suggest that climate change perception and behaviour influence and fed back on each other, and that farmers' risk perceptions are influenced by their risk exposure.

We ran two Probit models to analyse the change in climate change risk perceptions between 2010-11 and 2015-16. Independent variables included combinations of nine actual farm production actions between 2010-11 and 2015-16 and also controlled for a range of demographic, socio-economic and farm level characteristics. The nine farm production actions were defined as dummy variables: 1) selling land; 2) purchasing land; 3) selling water entitlements; 4) purchasing water entitlements; 5) increasing irrigated area; 6) decreasing irrigated area; 7) changing crop mix; 8) improving irrigation infrastructure; 9) utilising solar and battery technology for pumping irrigation water; and 10) climate change plan action (e.g.

[5] Unfortunately we had limited information on tree planting, soil management and other types of 'softer' farm adaptation behaviour because only farmers who answered they had a climate change risk plan were asked to provide more information on what they were doing as part of this plan. Given this, although a wide range of variables was included in the full regression modelling shown in Table A4 in the Appendix, it was not statistically significant and it limits any ability to fully infer insights. One such hypothesis is that more 'softer' farm adaptation behaviour (unlike other major production decisions) will not feed back negatively on climate change attitudes, due to the fact such behaviour is more diagnostic, knowledge-based and lower financial cost in nature (similar to findings in Nauges and Wheeler, 2017, regarding different types of household behaviour). Indeed, the coefficients in Table A4 provide some support that this type of farm adaptation behaviour has a positive feedback impact on climate change attitudes (but the results were not statistically significant and larger sample sizes will be needed).

tree planting, soil management etc). Pre-testing of the independent variables suggested that the farm actions of water entitlement trade and irrigation area had interaction effects. Therefore, in the reported models, two interaction terms were created between selling water entitlements and decreasing irrigated area, and purchasing water entitlements and increasing irrigated area.

Since the sample size of 275 irrigators is relatively small, the statistical power of our analysis may be low, which suggests a higher probability of failing to detect a statistically significant difference when such a difference actually exists (also called a type II error). Power calculations were undertaken for the variables of most interest to the study—climate change risk perception between 2010-11 and 2015-16, and irrigators' production decisions regarding water entitlements and irrigated area. Although our sample size is relatively small, for the purpose of our analysis, the statistical power is sufficient or close to sufficient (i.e. above or close to 0.80).[6] In line with best practices in the literature (Gabaix and Laibson 2008), a parsimonious model was estimated using the nine actual farm production actions between 2010-11 and 2015-16 if they are statistically significant (0.10 level) and only the statistically significant (0.10 level) control variables, such as education, state location, succession status, etc. However, for robustness check, another model using the full list of independent variables was estimated as well and reported in Table A4 in the Appendix.

[6] In our sample, there are 140 irrigators who did not sell water entitlements and did not reduce irrigated area, and 25 irrigators who did both. The proportion of group 1 (from Yes to otherwise) for the 140 irrigators is 0.04 while the proportion of group 1 for the 25 irrigators is 0.24. The power of a two-sided test to detect a statistically significant difference between the two proportions, assuming a 0.05 significance level is 0.85, which is above the usual 0.80 default level, suggesting the probability of committing a type II error is 0.15. Similarly, there are also 190 irrigators who did not buy water entitlements and did not increase irrigated area, and 19 irrigators who did both. The proportion of group 2 (from No to otherwise) for the 190 irrigators is 0.20 while the proportion of group 2 for the 19 irrigators is 0.48. The power of a two-sided test to detect a statistically significant difference between the two proportions, assuming a 0.05 significance level is 0.76, which is close to the usual 0.80 default level, suggesting a type II error probability is 0.24.

Table 5. Estimated coefficients of parsimonious probit models for change in climate change risk perception between 2010-11 and 2015-16

	Group One: From 'Yes' to otherwise		*Group Two: From 'No' to otherwise*	
	Marginal effect	***Delta-method Std. Err.***	***Marginal effect***	***Delta-method Std. Err.***
Sold farm-land in last 5 years	-	-	-0.192^{**}	0.090
Bought farm-land in last 5 years	0.169^{***}	0.045	-	-
Neither sold water entitlement nor reduced irrigated area (reference group) in the last five years	-	-	-	-
Only reduced irrigated area	0.016	0.043	-	-
Only sold water entitlements	0.080^{**}	0.035	-	-
Sold water entitlements and reduced irrigated area	0.146^{***}	0.039	-	-
Neither bought water entitlement nor increased irrigated area (reference group) in the last five years	-	-	-	-
Only increased irrigated area	-0.001	0.034	0.002	0.067
Only bought water entitlements	-0.185^{***}	0.071	0.079	0.088
Bought water entitlements and increased irrigated area	-0.123^{**}	0.062	0.187^{**}	0.084
Changed crop mix in last five years	0.104^{***}	0.032	-	-
Improved irrigation infrastructure in last 5 years	0.136^{**}	0.064	-	-
NSW state (SA and VIC reference group)	-	-	-0.192^{***}	0.059
Low education dummy in 2015-16[1]	0.114^{***}	0.035	-	-
Successor dummy in 2015-16[1]	-0.128^{***}	0.030	-	-
Permanent crop dummy in 2015-16[1]	0.062^{**}	0.029	-	-
Net farm income ($1,000) in 2015-16[1]	-0.001^{***}	0.0002	0.0006^{*}	0.0003
Debt to equity ratio in 2015-16[1]	-0.092^{**}	0.044	-	-
Total high security water entitlement (ML) in 2015-16[1]	0.0001^{***}	0.00004	-0.0002^{**}	0.0001
Change in water utilisation rate in last 5 years	-	-	0.001^{**}	0.0005
Mean rainfall percentile in the last 5 years (20km around farm)	0.009^{***}	0.003	-	-
Observations	275		275	
Wald Chi-2 statistics	39.08^{***}		24.41^{***}	
Pseudo R^2	0.38		0.08	
% of correct predictions	94		79	

[1] Variables in 2010-11 were also tried and results were similar for most. Since succession plan had 14 missing values in 2010-11, all these variables in 2015-16 were used instead. For model results with the full list of independent variables, refer to Table A4 in the Appendix. The models reported here were kept as parsimonious as possible.

***, **, * indicates statistical significance at the 1%, 5% and 10% level respectively.

Findings from the first (Group 1) Probit model (shown in Table 5) suggest that irrigators were more likely to change their original climate change risk perception from "Yes" to otherwise (including no and unsure) five years later if they bought farmland (with an increasing probability of 0.17), decreased irrigated area and meanwhile sold water entitlements (with a probability of 0.15), changed crop mix (with an increasing probability of 0.10), and improved irrigation infrastructure (with an increasing probability of 0.14). Irrigators were also less likely to change their original climate change risk perception from "Yes" to otherwise five years later if they bought water entitlements but did not increase irrigated area (with a decreasing probability of 0.19), or bought water entitlements and meanwhile increased irrigated area (with a decreasing probability of 0.12). This suggests support for decreased risk exposure from farm action - resulting in a weaker belief in climate change, or for increased risk exposure resulting in a stronger climate change risk perceptions. Other statistically significant results include farmers with low education were more likely to have switched from a believer to a denier/not sure, and those who had a succession plan in place were less likely to have switched from being a believer to denier/not sure. Higher net farm income and higher debt to equity levels - which suggest higher risk exposure from increased debt levels - are associated with a lower likelihood in switching from a believer to otherwise. A higher rainfall in the farm's location (decreased risk exposure) in the last five years was found to increase the likelihood in switching from a believer to otherwise.

Results of the second (Group 2) Probit model in Table 5 suggest that irrigators were more likely to change their original climate change risk perception from "No" to otherwise if they increased irrigated area and also consequently bought more water entitlements (with an increasing probability of 0.19), had an increased water utilisation rate and did not sell farmland – during the five years between 2010-11 and 2015-16. These results indicate that overall increased irrigation risk exposure from farm action means farmers were more likely to change from being a denier towards believing climate change poses a risk or being unsure. Although caution is recommended due to the small sample size, our results suggest that farmers' climate change perceptions may be influenced by farm production decisions that impact their risk exposure. But it is also important to note that it is possible that other variables beyond those able to be included in our regression models could also impact farmers' perceptions of climate-related risk.

Discussion

Although there has been much research in the literature on understanding the drivers of both consumers' and farmers' climate change beliefs (Austin et al. 2020a; Hornsey et al. 2016; Raymond and Spoehr 2013; van der Linden 2014), nearly all of this work has used snapshots of observed behaviour and beliefs at one point in time, making it difficult to study their dynamics within a specific population. There has also been increasing literature that has highlighted the complex relationship between attitudes and behaviour, and that undertaking climate change adaptation and mitigation action can sometimes feed back negatively on climate change attitudes (Nauges and Wheeler 2017; Wheeler et al. 2013). This study has extended the literature by using a panel dataset of the same 275 Australian farmers over a five-year period to explore and understand: a) the extent, stability and influences associated with farmers' climate change perceptions; and b) how farmers' climate change risk perceptions are associated with major farm changes – and to further test the potential feedback (endogenous) relationship between attitudes and long-term farm behaviour.

Overall, it was found that MDB farmers' perceptions towards climate change became more accepting over the five-year period (from 33% agreeing that climate change posed a risk to their region in 2010-11 to 46% in 2015-16). This is a positive sign for policy-makers trying to encourage increased farm adaptation, in the face of a hotter and more variable climate future.[7] Our analysis in this paper supports the role that farmer characteristics (e.g. education, has a farm successor) and farm characteristics (e.g. location, farm size, irrigated area, industry (permanent versus annual crops), debt, and climate conditions (temperature and rainfall)) play in driving climate change perceptions. The interplay between risk exposure and perceptions is revealing: MDB farmers in higher debt, with greater permanent crops, in areas that have had higher temperatures and less rainfall, were all more likely to accept climate change poses a risk to their region (similar to results found by Mase et al. 2017).

This study found some evidence that farmers who went from believers in 2010-11 to deniers/unsure in 2015-16, were more likely during the five years to change crop mix, upgrade irrigation infrastructure, reduce irrigated area and consequently sell water entitlements. We suggest this decreased their overall risk exposure and hence *negatively* fed

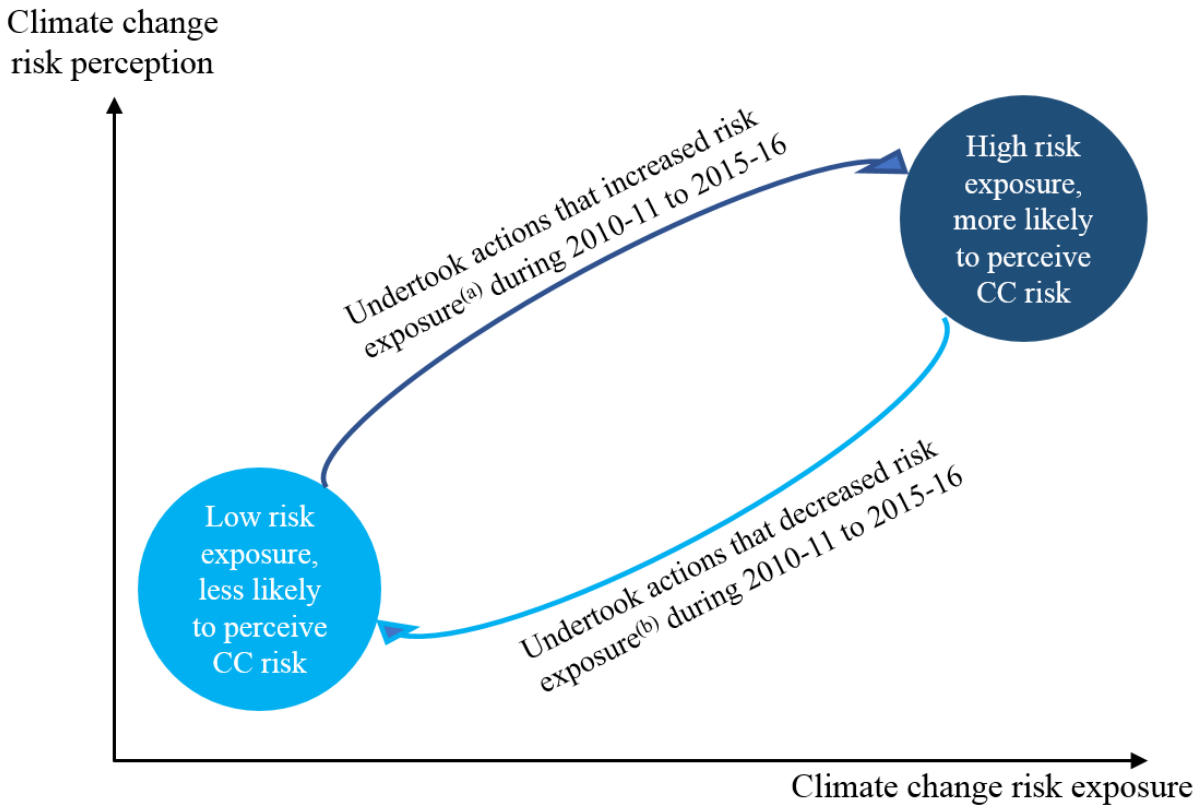
[7] Indeed, there is evidence in the past couple of years of increased action by farmers towards climate change, given that Australia has seen the creation of the following groups such as Young Carbon Farmers and Farmers for Climate Action. The country has also had the first ever rally on climate change by farmers in Canberra in 2018, national adverts in 2018 on the need for climate change action by farmers and since 2016 the National Farmers Federation have taken increasingly stronger positions on the need to reduce carbon emissions.

back on their stated climate change concern in 2015-16. Indeed, there may be some link between the presence of upgraded irrigation infrastructure (increasing the ‘sense of control’) and lessening climate change beliefs, as suggested by the findings of Niles and Mueller (2016). This study found evidence to suggest that the presence of infrastructure potentially positively influenced farmer perceptions that annual rainfall had increased over time. Niles and Mueller (2016) proposed these perceptions were important, with regards to how the presence of infrastructure influenced how people perceived and responded to climate change. The identification of a significant increase in water extraction of up to 28% by Wheeler et al. (2020a), from subsidising irrigation infrastructure in the southern MDB, indicates one such negative consequence of government policy.

Similarly, climate change deniers in 2010-11 were more likely in the following five years to increase irrigated area and consequently purchase water entitlements – plus increase their water utilisation rate, which in turn increased their overall risk exposure. This then correspondingly *positively* fed back on their stated climate change attitudes in 2015-16, and they became more concerned about the risk of climate change. Our findings echo Wilson et al. (1993)’s analysis of risk perception and management decisions of US dairy farmers as an outcome of complex feedback loops between perceptions and behaviour (van Raaij, 1981). It also complements recent findings by Austin et al. (2020b) on the dynamics of drought-related attitudes and adaptive capacity in the NSW non-metropolitan population. However, to the best of our knowledge, this is the first time a link between farm action and farmer attitude has been shown from any behavioural data over a period of years.

In regards to the relationship between attitudes and major farm production decisions, our main findings regarding the dynamics and relationships of exposure, perceptions and actions are summarised in Figure 2, which shows a feedback loop happening between attitudes and behaviour. We argue that this feedback from actions to perceptions is one reason to explain the instability in climate change perceptions. In our panel data sample, 43% of surveyed farmers did not have the same climate change perceptions five years later, and – although more farmers were likely to switch to agreeing that climate change posed a risk – it was also true that some reversed their former statement that climate change was occurring. Our findings also demonstrated that change in local weather conditions partly explained the change in climate-related risk perception.

Figure 2. Key summary of relationship between climate change (CC) risk perceptions, risk exposure and changed farm behaviour



Notes: [a]In particular, bought water entitlements and also increased irrigated area
[b]In particular, sold water entitlements and also decreased irrigated area

Whether farmers do or do not accept climate change, they all have to deal with the uncertainty of weather and, indeed, farmers have been managing uncertainty for a very long time. The question is how we can help farmers adapt the most to a changing climate in the future, understanding that there is a complex link between perceptions and behaviour. Given that the term 'climate change' can be so polarising, education campaigns to change farmers' perceptions will probably not provide the desired results – although it is clear from our results that higher farmer education in general is associated with more stability in climate change perception. George et al. (2019) recommended a focus on education, extension on risk management and developing best management practices for dealing with extreme climatic events. We also recommend an implementation of policies that improve farmers' risk-management and decision-making, by focusing on how adaptation to weather variability can increase profitability and strengthen the farm's viability. Similar to household behaviour (Nauges and Wheeler 2017), a portfolio of policies, regulation, targeted incentives and information is needed. Indeed, different populations of farmer cohorts may need a different mix of policies. Farming policy should be more strategic and forward thinking, with subsidies removed for inputs and outputs that can distort farmers' decision-making (e.g. Wheeler et al. 2020a for comments on irrigation infrastructure subsidies) – and reward farmers for good land practice (e.g. greater use and implementation of soil carbon markets and land stewardship). Many farmers are already making significant investment in planning for climate change on their farm, and the challenge for policy-makers is how to maximise such behaviour going forward.

The limitations of our study include the relatively small sample size (n=275), and the fact it only covers five years of farm data and attitudes. The small sample size also did not allow us to break up the data into typologies of farmers (e.g. traditional farmers versus environmentally friendly farmers versus corporate/profit minded farmers), nor industries for further analysis. We also had limited information on more diagnostic and knowledge forms of farmer adaptation behaviour (tree planting, changes of practices etc) – where with further data it would be very interesting to test for the existence of a negative (or indeed even a positive) feedback loop with climate change perceptions. The surveys were done in two very different climatic years, which, although this was controlled for in our modelling, may have had an impact on climate change risk perceptions. Further research in this space on the feedback loop between attitudes and behaviour for both consumers and farmers across developed and developing countries may be warranted, through a variety of different methods such as experimentation, repeated survey analysis and in-depth qualitative analysis.

Conclusion

The exact relationship between people's climate change attitudes and behaviour is a topic that is very important for climate change policy worldwide. Do climate change attitudes influence behaviour or is it possible that behaviour can change attitudes? If the influence is just one way, then education to try and change climate change attitudes may be one of the most effective ways of encourage adaptation to climate change. However, if there is a feedback loop between behaviour and attitudes, then more sophisticated policy instruments may be needed. There is emerging literature highlighting this complex relationship between attitudes and behaviour, and that undertaking climate change adaptation and mitigation action can sometimes feed back on climate change attitudes. However, the majority of the current literature that has studied these relationships have focussed on cross-sectional analysis (one-off surveys at a point in time). This study has extended the literature by using a panel (repeated survey of the same irrigators) dataset of 275 MDB farmers, over the time-period of 2010-11 to 2015-16, to examine the evidence for the existence of a feedback loop. It does so by exploring three main questions: 1) understanding farmers' climate change risk perceptions and the characteristics associated with their perceptions; 2) identifying how farmers' risk perceptions have evolved over time and how stable those risk perceptions are; and 3) identifying if climate change risk perceptions are associated with major farm action long-term changes.

It was found that farmers became more accepting of climate change risk in their region over the time-period (those agreeing increased from 33% to 46%). However, climate change perceptions were not stable: 41% of surveyed farmers in our panel dataset did not have the same climate change perception five years later, and although more farmers were likely to change to agreeing that climate change posed a risk, it was also true that some farmers reversed their former statement that climate change was occurring. This variability in attitudes is one reason why it has been found that attitudes are often not the major driver of behavioural change.

This study found new evidence of the feedback loop between perceptions and behaviour in Australia. Namely, farmers who believed at the start of the time-period that climate change was a risk, were more likely to undertake decisions that reduced their risk exposure overall (e.g. changed crop mix; upgraded irrigation infrastructure; and reduced irrigated area and consequently sold water entitlements). This correspondingly negatively fed back on their climate change concern (i.e. they became less concerned about the risk of climate change). Conversely, non-believers who increased their risk exposure over the time-period (e.g. increased water utilisation; increased irrigated land and consequently bought water entitlements) were more likely to change their mind afterwards and believe that climate change posed a risk.

Given these findings, and the similarities noted between our study and farmers' climate change perceptions in other developed countries, it is important that policy-makers worldwide understand the complex relationship between attitudes and behaviour, and how various policies to change behaviour can impact negatively (or positively) on attitudes. Going forward, policies that improve farmers' risk-management and decision-making by focusing on how adaptation to weather variability can increase profitability and strengthen the farm's viability will be highly important; and a portfolio of policies, regulation, targeted incentives for good land management and information is needed.

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Appendix

Table A1. Key characteristics of the full sample and panel sample in 2010-11

	Full sample (n=946)	Panel sample (n=275)
State: NSW	33% [30%, 36%]	36% [30%, 42%]
VIC	38% [35%, 41%]	39% [34%, 45%]
SA	29% [26%, 32%]	25% [20%, 31%]
Education level:		
Below year 10	16% [14%, 19%]	17% [13%, 22%]
Year 10 to year 12	52% [49%, 55%]	51% [45%, 57%]
Tafe and equiv.	12% [10%, 15%]	14% [10%, 18%]
Univ. and equiv.	19% [17%, 22%]	19% [14%, 24%]
Gender (male = 1)	88% [86%, 90%]	90% [86%, 93%]
Age (years)	55.0 [54.3, 55.7]	55.4 [54.2, 56.7]
Likelihood of successor (yes=1)	36% [32%, 39%]	38% [32%, 43%]
Environ. group member (yes=1)	26% [23%, 28%]	27% [21%, 32%]
Farm size (ha)	471 [410, 533]	506 [400, 613]
Irrigated size (ha)	144 [125, 163]	153 [120, 186]
Irrigation Land in permanent crops - grape and fruit trees (%)	31.6 [28.7, 34.5]	30.0 [24.7, 35.3]
Irrigation land in broadacre crops	23.3 [21.1, 25.6]	24.7 [20.3, 29.0]
Irrigation land in grazing and pasture	35.0 [32.2, 37.7]	35.1 [30.1, 40.0]
Total volume of high entitlement water held (ML)	294 [259, 329]	297 [250, 344]
Net farm income(AU$1,000)	30.4 [28.5, 32.3]	33.8 [30.2, 37.5]
Off-farm income (% of total income)	40.1 [37.6, 42,7]	38.9 [34.3, 43,6]
Debt to equity ratio	0.42 [0.39, 0.44]	0.40 [0.35, 0.44]

Note: The 95% confidence intervals are in square parentheses, which overlap each other between the full sample and panel sample, suggesting they do not differ statistically significantly with regard to any of the characteristics above.

Table A2. Distribution of farmers' perception on risk posed by climate change in 2010-11 and 2015-16 (full sample)

	2010-11		2015-16	
	Freq.	**Percent**	**Freq.**	**Percent**
No	455	48	352	35
Yes	304	32	435	44
Unsure	187	20	213	21
Total	**946**	**100**	**1,000**	**100**

Table A3. Summary statistics for all variables in the probit models of Table A4 (n=275)

	Obs	*Mean*	*Std. Dev.*	*Min*	*Max*
Dependent variable					
Group One: From ‘Yes’ to otherwise	275	0.073	0.260	0	1
Group Two: From ‘No’ to otherwise	275	0.233	0.423	0	1
Independent variable					
Sold farm-land in last 5 years	275	0.113	0.317	0	1
Bought farm-land in last 5 years	275	0.215	0.411	0	1
Neither sold water entitlement nor reduced irrigated area (reference group) in the last five years					
Only reduced irrigated area	275	0.167	0.374	0	1
Only sold water entitlements	275	0.233	0.423	0	1
Sold water entitlements and reduce irrigated area	275	0.091	0.288	0	1
Neither bought water entitlement nor increased irrigated area (reference group) in the last five years					
Only increased irrigated area	275	0.149	0.357	0	1
Only bought water entitlements	275	0.091	0.288	0	1
Bought water entitlements and increased irrigated area	275	0.069	0.254	0	1
Changed crop mix in last five years	275	0.527	0.500	0	1
Improved irrigation infrastructure in last 5 years	275	0.804	0.398	0	1
Utilised solar and battery technology in last 5 years	275	0.098	0.298	0	1
VIC state (NSW reference group)	275	0.393	0.489	0	1
SA state (NSW reference group)	275	0.251	0.434	0	1
Age in 2015-16	275	60.553	10.662	25	84
Male gender dummy in 2015-16	275	0.898	0.303	0	1
Low education dummy in 2015-16	275	0.167	0.374	0	1
Environmental group membership dummy in 2015-16	275	0.196	0.398	0	1
Successor dummy in 2015-16	275	0.378	0.486	0	1
Farm size (ha) in 2015-16	275	701.043	1962.424	0	20193.83
Permanent crop dummy in 2015-16	275	0.342	0.475	0	1
Irrigated area (ha) in 2015-16	275	267.464	625.786	0	8000
Total high security water entitlement (ML) in 2015-16	275	251.891	370.592	0	2000
Net farm income ($1,000) in 2015-16	275	81.226	79.781	0	250
Debt to equity ratio in 2015-16	275	0.313	0.402	0	3
Mean end allocation % in last 5 years	275	0.856	0.278	0	1
Change in water utilisation rate in last 5 years	275	20.658	43.449	-100	100
Mean rainfall percentile in the last 5 years (20km around farm)	275	55.276	4.359	44	66
Climate Change Actions−Have undertaken actions in response to climate change risk in 2015-16: planting trees; installing canopy/shed for plant/livestock shelter; soil management; or changing timing of agricultural practices (1=yes, 0=no)	275	0.07	0.25	0	1

Table A4. Estimated marginal effects of Probit models for change in climate change risk perception between 2010-11 and 2015-16, with full list of independent variables

	Group One: From 'Yes' to otherwise		***Group Two: From 'No' to otherwise***	
	Marginal effect	***Delta-method Std. Err.***	***Marginal effect***	***Delta-method Std. Err.***
Sold farm-land in last 5 years	-0.026	0.037	-0.247^{***}	0.085
Bought farm-land in last 5 years	0.176^{***}	0.049	-0.015	0.066
Neither sold water entitlement nor reduced irrigated area (reference group) in the last five years				
Only reduced irrigated area	0.028	0.042	-0.035	0.069
Only sold water entitlements	0.090^{***}	0.033	-0.104	0.065
Sold water entitlements and reduced irrigated area	0.154^{***}	0.037	0.048	0.090
Neither bought water entitlement nor increased irrigated area (reference group) in the last five years				
Only increased irrigated area	0.013	0.035	0.004	0.069
Only bought water entitlements	-0.153^{**}	0.068	0.062	0.089
Bought water entitlements and increased irrigated area	-0.122^{**}	0.060	0.190^{**}	0.095
Changed crop mix in last five years	0.111^{***}	0.031	-0.0003	0.049
Improved irrigation infrastructure in last 5 years	0.133^{**}	0.067	0.020	0.068
Utilised solar and battery technology in last 5 years	0.033	0.036	-0.041	0.083
VIC state (NSW reference group)	0.049	0.048	0.253^{***}	0.071
SA state (NSW reference group)	0.005	0.047	0.214^{**}	0.088
Age in 2015-16[1]	0.0001	0.002	0.0002	0.002
Male gender dummy in 2015-16[1]	0.009	0.042	-0.021	0.079
Low education dummy in 2015-16[1]	0.116^{***}	0.035	0.085	0.066
Environmental group membership dummy in 2015-16[1]	-0.058	0.045	0.036	0.056
Successor dummy in 2015-16[1]	-0.132^{***}	0.036	-0.105^{**}	0.055
Farm size (ha) in 2015-16[1]	-0.000001	0.00001	0.00001	0.00002
Permanent crop dummy in 2015-16[1]	0.085^{**}	0.039	-0.120^{*}	0.068
Irrigated area (ha) in 2015-16[1]	-0.00003	0.00005	-0.000003	0.00005
Total high security water entitlement (ML) in 2015-16[1]	0.0001^{***}	0.00004	-0.0002^{***}	0.0001
Net farm income ($1,000) in 2015-16[1]	-0.001^{**}	0.0002	0.001^{*}	0.0003
Debt to equity ratio in 2015-16[1]	-0.094^{**}	0.041	0.096	0.066
Mean end allocation % in last 5 years	-0.060	0.051	-0.018	0.104
Change in water utilisation rate in last 5 years	0.0003	0.0004	0.001^{*}	0.001
Mean rainfall percentile in last 5 years (20km around farm)	0.010^{**}	0.004	-0.001	0.007
Climate Change Actions (e.g. tree planting; soil management; timing changes; canopy/shed for plant/shelter)	-0.073	0.057	0.056	0.092
Observations	275		275	
Wald Chi-2 statistics	68.71^{***}		42.82^{**}	
Pseudo R^2	0.42		0.14	
% of correct predictions	94		79	

[1] Variables in 2010-11 were also tried and results were similar for most. Since succession plan had 14 missing values in 2010-11, all these variables in 2015-16 were used instead.

***, **, * indicates statistical significance at the 1%, 5% and 10% level respectively.