Past experience of drought, drought risk perception, and climate adaptation policies by farmers in New Zealand

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Abstract: We analyze the perception of farmers in New Zealand with regards to future drought risk as shaped by climatic change and the implications of these perceptions for climate adaptation actions that these farmers choose to pursue. The adaptation options examined include reducing greenhouse gas emissions, strengthening climate resilience, and using water resources more efficiently. Almost all farmers in New Zealand expect an increase in drought frequency and intensity by 2050. We also find that age, gender, and education are correlated with future drought risk perceptions by farmers. Female farmers and farmers with higher education are more concerned about future droughts. Importantly, drought perception of farmers is associated with their adaptation choices to climate change. If farmers perceive an increase in drought risk by 2050, they will focus more on reducing greenhouse gas emissions, increasing the climate resilience of their farms, and trying to improve their use of water resources. Understanding how drought risk perceptions are shaped, and specifically their role in determining adaptation decisions, may shed some useful light that can improve policy responses to the risks of droughts and climate change more broadly.

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Keywords: Drought risk, climate change, agricultural drought, perception, adaptation

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1. Introduction

The weather in Aotearoa - New Zealand (NZ) is diverse, with comparatively mild temperatures year-round in most of the country (except for the high-altitude inland areas) and with strong winds that lead to frequent weather changes. A variety of natural hazards - droughts, earthquakes, tsunamis, and floods - lead to significant adverse consequences to people and to the economy. Drought in particular occurs regularly, especially in summer, and has significant adverse consequences for the rural economy (Salinger & Porteous, 2014). Because of climate change, droughts are projected to increase in both frequency and intensity in most of the country (MfE, 2018)[1], and especially in the most agriculturally productive areas. As such, it is inevitable that farmers will increasingly need to adapt, even in the most optimistic climate scenarios.

Understanding the perception that farmers have about drought frequency and intensity is a necessary step for shaping any policy that may lead to any improvement in farmers' climate adaptation responses.[2] This study analyzes farmers' perception of drought risk based on survey data and a drought risk index constructed by New Zealand's National Institute of Water and Air (NIWA). In addition, the study estimates the effect of drought perception on some of the main plausible adaptation actions for climate resilience and sustainable water use.

This study thus has two main objectives: (1) To identify the factors underlying farmers' perceptions of future drought risk, and (2) To examine how perceptions of drought risks associate with farmers' climate adaptation and mitigation actions, climate resilience, and sustainable water use.

The paper is structured as follows: Section 2 provides a literature review on drought perception in high-income countries in general and in New Zealand in particular. Section 3 presents the data source and sample. Section 4 describes the methodology, section 5 presents the empirical results, and section 6 provides some concluding discussion.

2. Literature Review

Drought reduces the availability of water for agricultural production and for the generation of hydroelectric energy, and thus employment and incomes (Hendy et al., 2018). Droughts can thus

[1] Ministry for the Environment (MfE) (2018). *Climate Change Projections for New Zealand: Atmosphere Projections Based on Simulations from the IPCC Fifth Assessment, 2nd Edition*. Wellington: Ministry for the Environment.
[2] The term "farmers" is used expansively to include all the participants in the survey we analyze below, including farmers, foresters, and growers as well as "lifestyle block" owners (i.e., 'hobby farmers').

have a negative impacts on the financial position of households, and consequently on economic growth (Edwards et al., 2009). In New Zealand, the severe drought in 2013 was estimated to have lowered annual GDP by 0.3%, mostly due to a fall in agriculture production (Kamber et al., 2013).[3]

Understanding the perception of drought risks by farmers is important for any attempt to reduce droughts' adverse impacts. A few papers have analyzed drought risk perceptions by farmers in high-income countries.[4] The first, Saarinen Thomas (1966), was about drought perceptions of farmers on the North American Great Plains. Two decades later, Taylor et al. (1988) undertook a follow-up farm survey similarly observing that the perception of risk is significantly impacted by expectations of future droughts and experience with drought in the past. In Spain, Urquijo and De Stefano (2016) interviewed farmers to examine the impact of water sources on farmers' drought perception. They found that the type of water source used in irrigation (e.g., groundwater or surface water) significantly affected farmers' perception of drought risk and consequently the type of adaptation strategies they prefer. In the Netherlands, Duinen et al. (2015) obtained data on risk perceptions, farm characteristics, and personality traits of farmers. They also ascertained that a high frequency of drought in the past led to higher current risk perceptions of farmers.

Some studies have noted that demographic and social characteristics such as age, education, gender, and farming experience are important determinants of individuals' perceptions of climate change (Acquah & Onumah, 2011; Borick & Rabe, 2010; Hamilton et al., 2018; Hornsey et al., 2016; Mase et al., 2017; Roco et al., 2015). For example, being younger, college-educated, and female considerably increases the probability that individuals in the US perceive that the earth is warming (Deryugina, 2013). Moreover, those who have experienced warmer-than-normal temperatures believe more strongly that global warming has been occurring (Deryugina, 2013). Borick and Rabe (2010) and Demski et al. (2017) indicated that personal experiences with extreme weather or natural hazards influence people's actions toward environmental protection.

Many papers argue that perception of climate change has an important role in shaping adaptation and mitigation by farmers (Arbuckle et al., 2013; Mase et al., 2017; Menghistu et al., 2018; Niles et al., 2013; Prokopy et al., 2015; Vainio & Paloniemi, 2013; Woudenberg et al., 2008). For instance,

[3] However, in some cases, drought has had only a moderate effect or possibly even positive financial implications. As an example, in the aftermath of the 2013 drought, higher prices for milk solids had positive revenue and profit consequences for New Zealand dairy farmers Pourzand, F., Noy, I., & Sağlam, Y. (2020). Droughts and farms' financial performance: a farm-level study in New Zealand. *Australian Journal of Agricultural and Resource Economics*, *64*(3), 818-844. .

[4] Droughts in lower-income countries, where many households depend on subsistence agriculture, have very different micro- and macro-economic impacts. This paper examines a high-income country (New Zealand) and therefore we also do not review the voluminous literature on droughts in lower-income countries.

Niles et al. (2013) surveyed 162 farmers in California to identify whether the perception of climate change directly affected farmers' responses to climate policy. Also, Mase et al. (2017) analyzed a 2012 survey of nearly 5000 corn farmers across 22 Midwestern U.S. watersheds and observed that risk perception played a crucial role in their adaptation attitudes and behaviors. Some research observed decisive effects of perception of drought risk on adaptation (Carlton et al., 2016; Switzer & Vedlitz, 2017; Taylor et al., 1988) and concluded that drought risk perception influenced farmers' preparation for drought.

There are very few studies on the perception of disaster risks and climate change in New Zealand. Niles and Mueller (2016) used climate data from various weather stations and farm surveys from the Marlborough and Hawke's Bay regions to show that a high share of farmers perceived a gradual increase in yearly summer temperatures, and these perceptions were closely related to personal and environmental factors. They concluded that understanding how farmers' perceptions interact with observed climate trends, irrigation infrastructure, and concern about climate change is necessary for improved decisions about adaptation measures. Lawrence et al. (2014) examined flood experience, flood risk perception, and households' responses in the Hutt Valley (a mostly suburban residential region) through a household survey and interviews with local government employees. Their findings illustrate that the more flood experience people had, the higher risk they perceived, and the more these led to increased disaster preparedness.

Booth et al. (2020) used the cross-sectional 2015 Survey of Rural Decision Makers and potential evapotranspiration deficit (PED) for 17 regions to estimate the impact of drought experience on drought expectation in 2050 while Stahlmann-Brown and Walsh (2022) employed the 2017 and 2019 waves of the Survey of Rural Decision Makers and the New Zealand Drought Index (NZDI) at more than 60 weather stations to investigate the effect of soil dryness on drought expectation of farmers, foresters, and growers. The dependent variables in both papers are binary variables noting whether respondents believe that drought will likely increase by the year 2050 and an ordered set of possible drought expectations in 2050, including decrease a lot, decrease slightly, no change, increase slightly, and increase a lot.

In the perception (first) part of the paper here, we use the same ordinal dependent variables of drought belief as the two previous papers. In terms of independent variables, Booth et al. (2020) used percent difference of 2015 average PED from the previous 5 and 10 years, personal characteristics of farmers, land that was leased or not, and type of water. Stahlmann-Brown and Walsh (2022) utilized the difference in the maximum monthly NZDI in 2017 and 2019 and the value of soil dryness. Booth et al. (2020) showed that the intensity of past droughts and the expectations of future droughts were significantly correlated and the extent to which current conditions differ from the long-term trend matters very little. Moreover, by using panel data to control for all of the time-invariant and unobserved heterogeneity, Stahlmann-Brown and Walsh (2022) found that low soil moisture contributes to an increased expectation of future droughts.

We use cross-sectional data from the 2019 wave of the Survey of Rural Decision Makers and the NZDI data from 2009 to 2018 to estimate the determinants of farmers' perception of drought frequency and intensity. Specifically, our hypothesis is that the recent (10 years) history of drought experience is important in shaping perceptions about future drought risk. Our study utilized the 2019 survey and daily drought data from NIWA to identify the variables that influence drought perception and climate adaptation.

The first contribution of this paper is to use more comprehensive drought daily data at district-level rather than yearly average data at region-level as Booth et al. (2020) did. Daily drought data better reflects the actual drought experience that matters for agricultural productivity by measuring the number of days with drought that farmers may have experienced. The higher spatial resolution we use is also important given the differences in weather conditions across relatively short distances in the complex topography in New Zealand.

Our second contribution, which is also the second part of the paper, is to investigate the adaptation measures related to climate that farmers employ or plan to employ. Similarly to the climate change perception question, we examine how perceptions of drought risks associate with farmers' climate adaptation and mitigation actions including reducing greenhouse gas emissions, investing in climate resilience, and investing in sustainable water use.

3. Data source and sample

3.1. Survey of Rural Decision Makers

The Survey of Rural Decision Makers has been conducted every two years since 2013. The survey is enumerated online to farmers, foresters, and growers, including both commercial operators and those in small non-commercial farms. The questionnaire emphasizes land use, land-use change, and drivers and barriers of land-management practices, but it also includes topics of contemporary policy interest, including risk management and climate issues, which are our focus here.

The 2019 survey was open from July until November 2019 to account for seasonal demands across the primary sector. It yielded 3,740 responses in all 66 districts in New Zealand, with about 1,530 responses from commercial farming/forestry and 1,720 responses from non-commercial farmers (Stahlmann-Brown, 2019). According to StatsNZ, there are about 50,000 commercial farms, forests, and growing operations in NZ in 2019.[5]

The questionnaire can be answered on a computer, a tablet, or a smart phone. Since the survey is conducted online, a lack of accessibility, especially for farmers from more remote areas, may be of concern. However, by 2016, 90% of rural New Zealanders had home access to broadband, and this number is scheduled to reach a target 99.8% by the end of 2022 (Crown Infrastructure Partners, 2018). The survey was also optimized for mobile devices to ensure accessibility for those without home internet access. All of the dependent variables we analyze - about drought perception and change of adaptation actions the next 5 years - are from the 2019 survey.

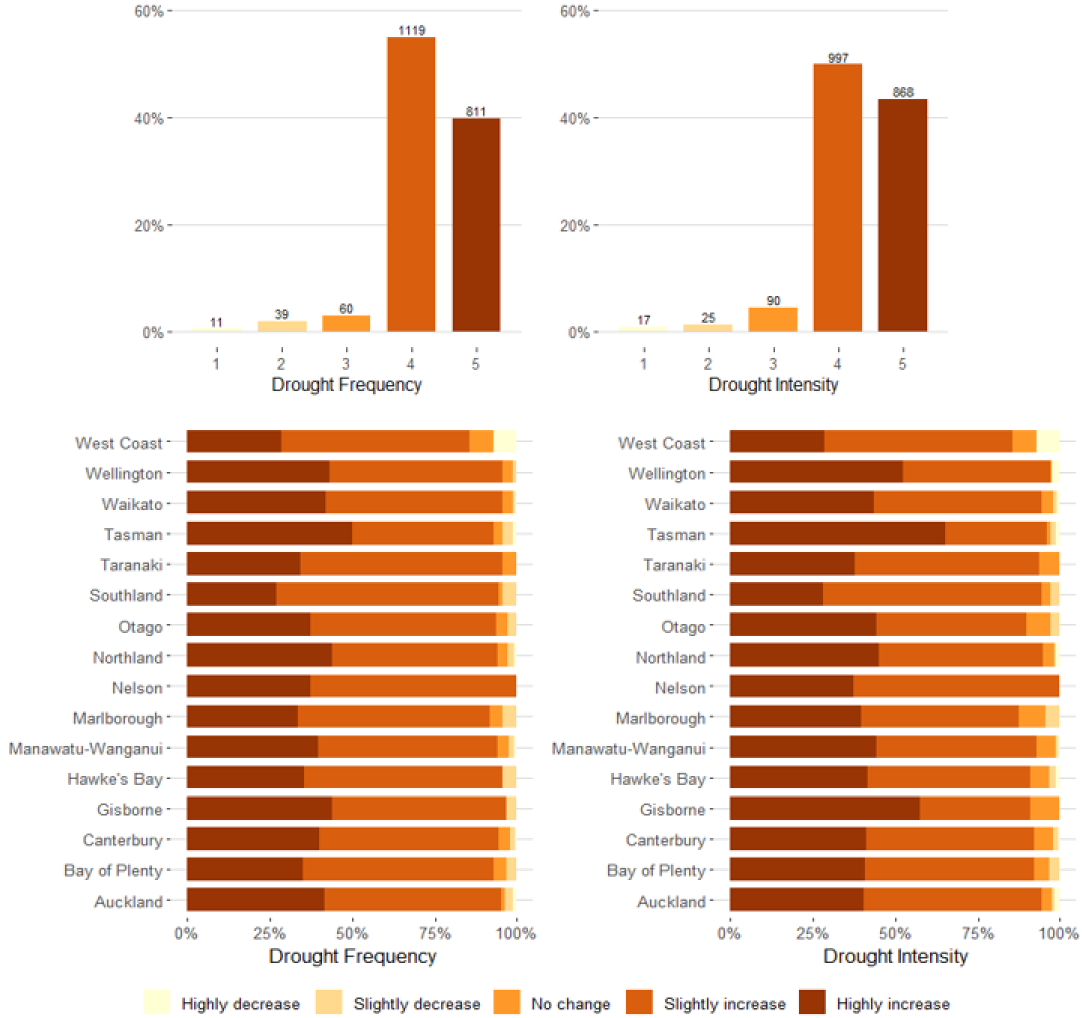
Dependent variables

The first dependent variable measures risk perception with respect to drought frequency and intensity by 2050. The question in the survey is "How do you personally expect the frequency and intensity of drought to change by 2050?". Farmers answered this question by choosing from: decrease a lot (1), decrease slightly (2), no change (3), increase slightly (4), increase a lot (5), and unsure (6). This study will consider "unsure" as missing values and remove them.

The summary of responses in Figure 1 indicates that a large majority of farmers believe that drought frequency and intensity will slightly or highly increase in the future with "slightly increase" being the most frequent response (55% and 49% of respondents for drought frequency and intensity, respectively). The figure also distinguishes the different perceptions of farmers by region. We can observe that the West Coast region has the highest rate of farmers who think drought frequency and intensity will not increase in the future, though even there, this group is still a small minority.

[5] https://www.stats.govt.nz/indicators/farm-numbers-and-size

Figure 1: **Perception of Drought Frequency and Intensity by 2050**[6]



The second dependent variable records whether farmers are focused on climate challenges. Survey respondents described the extent to which "reducing greenhouse gas emissions", "becoming more resilient to changing climate", and "using water more efficiently" were focuses for their operations over the previous five years and whether they would be a focus over the next five years. The scale used is: (1) not much of a focus, (2) minor focus, (3) moderate focus, (4) major focus. Here, we consider the reported focus in the next 5 years to see how farmers' plans and actions in the future may be impacted by drought experience and drought perception. The summary of the values in Table 1 reveals that most farmers have a moderate focus on climate resilience, greenhouse gas emission and water use, at 44.3%, 32.9% and 36.7%, respectively.

[6] People who selected "climate change will not affect NZ" did not answer the question related to perception of drought by 2050. This figure removed all missing values of the question "How do you personally expect the frequency and intensity of drought to change by 2050?"

Those that devote a ‘major focus’ to climate resilience and water use rank second at 23.2% and 28.65%. A major focus on reducing greenhouse gas emission is the lowest at 13.2%. At this point, farmers pay attention more to climate resilience and efficient water use. Moreover, 23.3% of farmers chose ‘not much of focus’ on greenhouse gas while these choices on climate resilience and water use was the lowest, at 8.22% and 11.4%, respectively.

Table 1: **Focus on climate challenges in the next 5 years (%)**

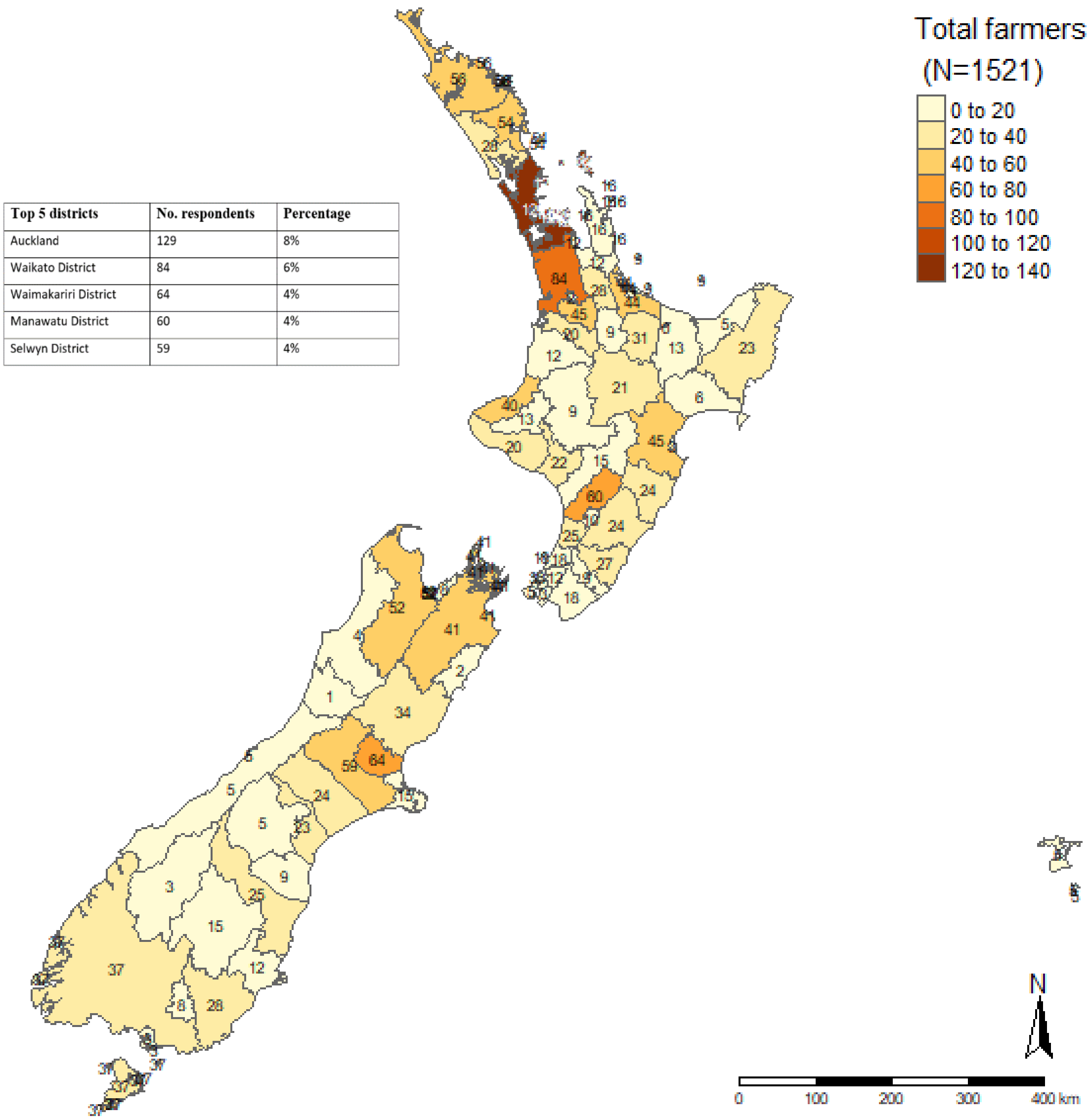
Focus in the next 5 years	Becoming more resilient to changing climate	Reducing greenhouse gas emission	Using water more efficiently
Not much of a focus	8.22	23.3	11.4
Minor focus	21.5	30.6	19.3
Moderate focus	44.3	32.9	38.2
Major focus	26.0	13.2	31.1
Total	1521	1521	1521

Independent variables

Table 2 describes the independent variables used in this study, including the personal characteristics of farmers based on survey data and the number of drought days experienced in each farm based on the NZDI. We compute the total drought days of districts in New Zealand based on data from NIWA. Then we create the binary variables for droughts that districts experienced. In addition, we categorise farmers by agre group as follows: <40, 40-50, 51-60, 61-70, 71+. We choose <40 as the reference group.[7] On-farm experience and total area are continuous variables, which indicate the years' farmers spend on their farm and the total area they own or lease. Gender and education level are categorical variables (male and tertiary education degree, respectively). The data for the number of respondents in each of New Zealand’s 66 districts is shown in Figure 2.

[7] 7% farmers are “<40 years old”, 17% of “40-50 years old”, 32% of “51-60 years old”, 31% of “61-70 years old”, 13% of “+70 years old”

Figure 2: **Number of respondents in the survey after removing all missing values**



Top 5 districts	No. respondents	Percentage
Auckland	129	8%
Waikato District	84	6%
Waimakariri District	64	4%
Manawatu District	60	4%
Selwyn District	59	4%

Table 2: **Descriptive statistics (N=1521)**

	Mean	Std dev	Min	Max
Age (years)	58.40	11.26	18	93
On farm Experience (years)	26.23	14.82	0	70
Male (=1)	0.68	0.47	0	1
Bachelor's degree or more (=1)	0.42	0.49	0	1
Total Area (ha)	216.5	1072.65	0.2	24000
Drought Experience (days)				
2010	31.73	34.48	0	96
2011	1.34	3.23	0	15
2012	0	0	0	0
2013	26.06	27.19	0	80
2014	9.81	18.51	0	61
2015	6.96	12.3	0	53
2016	0.16	1.15	0	22
2017	9.87	12.91	0	48
2018	5.37	7.82	0	31
From 2010 to 2018	91.34	72.14	0	257
From 2015 to 2018	22.37	18.95	0	81

3.2. New Zealand Drought Index

NIWA constructs the NZDI from four existing indicators: the Standardized Precipitation Index (SPI), the Soil Moisture Deficit (SMD), the Soil Moisture Deficit Anomaly (SMDA), and the Potential Evapotranspiration Deficit (PED).

According to NIWA[8], "SPI is based on the comparison between precipitation for a given time and the long-term precipitation. The 'standardized' means precipitation differences are divided by the long-term standard deviation of precipitation. SMD is based on incoming daily rainfall (mm), outgoing daily potential evapotranspiration (PET, mm), and a fixed available water capacity (the amount of water in the soil 'reservoir' those plants can use) of 150 mm". SMDA (SMD Anomaly) is calculated with respect to the 30-years SMD normal (Mol et al., 2017). The PED is computed based on the difference between PET and AET. AET is the water loss in the surface by evaporation from soils and plants (Rana & Katerji, 2000).

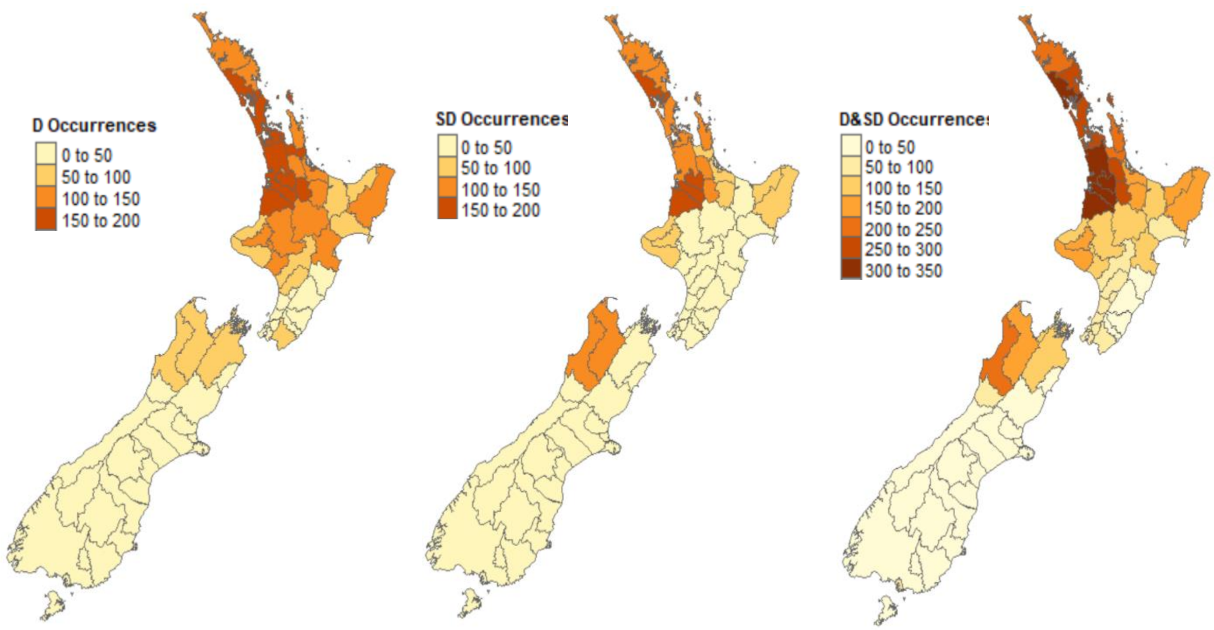
[8] https://niwa.co.nz/climate/nz-drought-monitor/droughtindicatormaps/Standardised%20Precipitation%20Index%20(SPI)

The differences between the four indicators are related to scale and sensitivity (Mol et al., 2017). According to Mol et al. (2017), the SMD and PED show positive values of water shortage while the SPI and SMDA have both positive and negative values. Moreover, the SPI scale is more sensitive to drier conditions. The NZDI is calculated as an average of the four indices (Mol et al., 2017). NZDI is a continuous variable from 0 to 2 with five categories as dry (>=0.75), very dry (>=1), extremely dry (>=1.25), drought (>=1.5), severe drought (>=1.7). It is recorded daily in 76 stations in New Zealand since 2007. In this study, we consider the appearance of drought and severe drought, so we focus on episodes when the NZDI exceeded 1.5.

Drought Frequency in New Zealand

We first analyze drought frequency by counting drought and severe drought days from the NZDI. Figure 3 shows our calculation for drought days from 2007 to 2020 by regions in New Zealand according to three parts: "D" (drought), "SD" (severe drought), "All Droughts" (both D and SD)[9]. The northern part of the North Island experienced more drought days and more severe drought days, especially Waikato with the highest number of both S/SD days.

Figure 3: **Total numbers of drought days, severe drought days, and both in NZ (2007-2020)**



Source: Own calculation from NIWA dataset

Figure 4 shows the frequency of drought days by months in the period 2007-2020; drought mostly happens from December to April with the highest frequency in February and March. Figure

[9] According to NIWA, NZDI >=1.5 is drought day and NZDI >=1.75 is severe drought day.

5 shows the total number of drought and severe drought days in all districts, with the highest numbers observable in 2010, 2013, and 2020. **Error! Reference source not found.** presents the frequency of districts experiencing droughts from 2007 to 2020. Over 14 years, droughts occurred in all 16 regions of New Zealand. Northland, Auckland, Waikato, and Bay of Plenty had the highest number of districts with drought in 2010, 2013, and 2020.

Figure 4: **Drought frequency in NZ by months (2007-2020)**

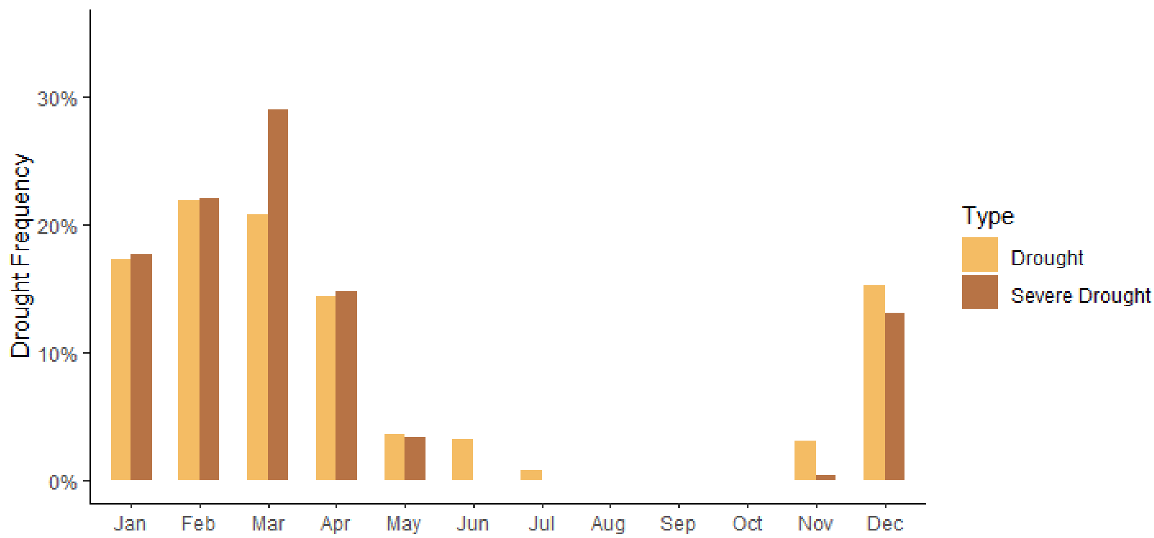
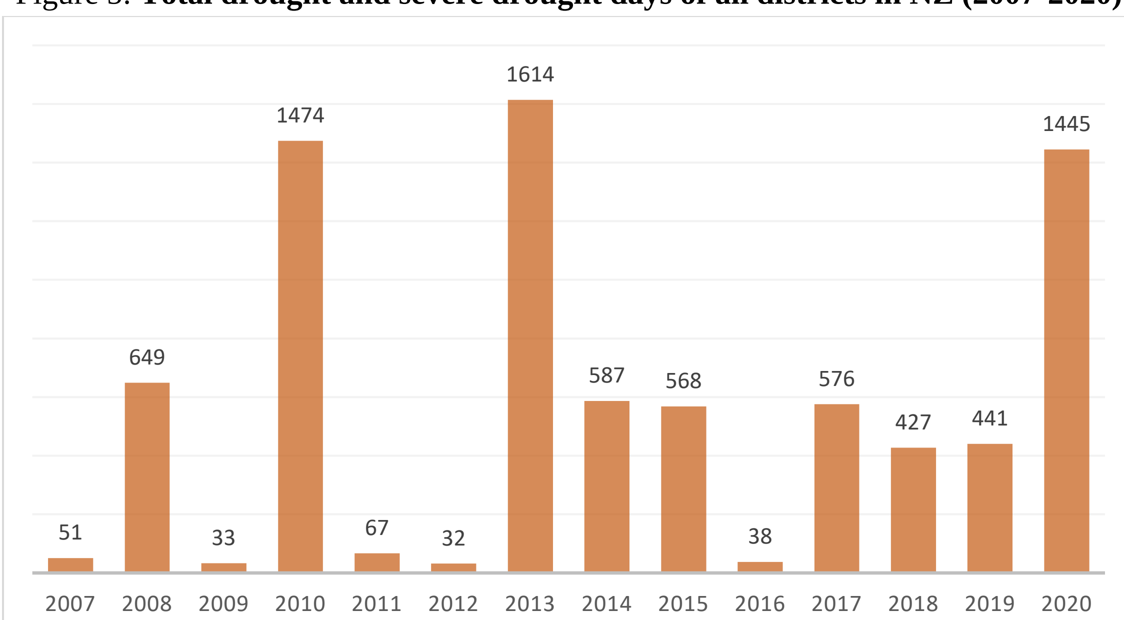


Figure 5: **Total drought and severe drought days of all districts in NZ (2007-2020)**



4. Empirical model

Since the dependent variables of both drought perception and focus are ordinal, we use ordinal logistic regression. To interpret results, we calculate the odds ratio (OR) by exponentiating each side of the models. An odds ratio that is less than 1 indicates that the odds of a lower response will increase when the predictor rises by one unit while the odds ratio being higher than 1 shows the opposite. If the OR is equal to 1, there is no difference between the two levels of response when the predictors change.

4.1. Drought perception

The regression equation to estimate drought perception is:

$$\log\left(\frac{P(Y_{ij} \leq k)}{1 - P(Y_{ij} \leq k)}\right) = \beta_1 Z_{ijt} + \beta_2 \vec{X}_{ij} + \varepsilon_{ij} \quad (1)$$

where Y_{ij} is the dependent variable measuring risk perception with the level being indexed by k = 1,2,3,4 for individual farmer i, in district j. X_{ij} is a verctor of personal characteristics, including age, on-farm experience, gender, education level, total owned land, and leased land area of farmer i in district j. Z_{ijt} is a vector of drought measures experienced by farmer i in district j in years t. This is defined as the number of days of drought (NZDI≥1.5), or the difference between the number of drought days 2019 and the average of the previous 5 years or 10 years. We estimate 5 models with different definitions for the drought variable: total drought days of each year, total drought days from 2014 to 2018 (5 years), from 2009 to 2018 (10 years), and difference of drought days between 2019 and the average previous 10 years (2009-1018) and previous 5 years (2014-2018). ε is the error term.

Ordinal logistic regression requires that the proportional odds (PO) assumption is not violated. To test the PO assumption in our models, we utilize the Brant test with package Brant and function brant() in R programming. The test result for the perception of drought frequency variable can be seen in Appendix Table 2. The results of Chi-square value of three models show that the assumption of proportional odds cannot be rejected. Appendix table 3 indicates the results for perception variables of drought intensity. Models are the same as in Appendix Table 2 with only different independent variables between drought frequency and drought intensity. The P-values of these models are larger than 5%, meaning that the proportional odd assumptions in these models cannot be rejected and the ordinal logistic model can be used.

4.2. Focus on climatic issues in the future

The dependent variable of the farmers' future adaptation focus is ordered from 1 to 4 with the scale:(1) not much of a focus, (2) minor focus, (3) moderate focus, (4) major focus (as in Table 1). Our purpose in this part is to estimate the association between drought perception and drought experience on the decisions of farmers on the three adaptation activities: "becoming more resilient to changing climate", "reducing greenhouse gas emissions", and "using water more efficiently". The regression equation is:

$$\log\left(\frac{P(A_{ij} \leq k)}{1 - P(A_{ij} \leq k)}\right) = \beta_1 Z_{ijt} + \beta_2 \vec{X}_{ij} + \beta_3 D_{ij} + \varepsilon_{ij} \quad (2)$$

where A_{ij} is the dependent variable, meausuring the focus of adaptation with k = 1, 2, 3, 4. X_{ij} and Z_{ijt} are the same as in model (1). D_{ij} is a dummy variable indicating whether droughts in 2050 are expected to increase. The Brant tests for the models of equation (2) are included in Appendix Tables 4 and 5. Chi-square values and p-value in all models indicate that the PO assumptions are not violated, and we can use the ordinal logistic regression for these models.

5. Results

5.1. Perception of drought frequency and intensity

Table 3 shows the regression results of perception of drought frequency and intensity. Columns (1)-(5) are the ordinal logistic regressions of frequency perception while columns (6)-(10) are the regressions of drought intensity. The main independent variables in these different models are drought experience in the past since we aim to identify the relevance of past experience with drought for perceptions of drought risk among farmers.

In columns (1) and (6), we consider the drought experience of separate years. Since there were few drought-affected districts in 2009, 2011, 2012, and 2016 (see figure 4), we do not include these years in the estimated model. Our purpose is to see if the drought in any particular year (e.g., 2013 which had the most intense drought) relates to the perception of drought risk by farmers. Consistently, we find that the odds ratios (ORs) of different years are insignificant, indicating that these annual drought experiences are not associated with the perception of drought risk. These results are robust to several alternative definitions of the variables of interest (see Appendix Table 6) and regression without control variables (see Appendix Table 7).

Additionally, columns (2) and (7) represent the regression with the predictor variable of total drought experience for the long period 2009-2018. Our hypothesis was that if people experience more drought days in the past, they will tend to perceive drought risk to be higher (in terms of both intensity and frequency) in the future. However, the result shows that the OR of drought experience in the period 2009-2018 is insignificant, meaning that the frequency of droughts over the past decade is not associated with farmers' perceptions. Moreover, columns (3) and (8) with drought experience in the more recent past (2014 to 2018) provide similar results - there is no relationship between drought experience and the perception of drought risk by farmers.

Columns (4) and (9) consider dependent variables of difference of drought days between 2019 and average of drought days in the previous 10 years from 2009 to 2018 while columns (5) and (10) show difference between 2019 and average of drought days in the previous 5 years. The ORs of these differences for models (4) and (5) are insignificant but these ORs for models (9) and (10) are significant at a 5% level (OR=1.008), meaning that if there is an increase in the drought days compared to the past, farmers perceive higher future drought risk. However, this relationship does not seem to have large real significance.

The ORs of age in 51-60, 61-70 years old (reference variable is <40 years old) are all significant and greater than 1 but the OR of the 40-50 and +70 years old is insignificant, representing that the older in 51-70 years old tend to have a higher perception of drought frequency and intensity in the future. The ORs of farming experience are significantly smaller than 1 at 0.99, so that if farmers have more years of farming experience (holding age constant), they will reduce their perception about the future frequency and intensity of drought (by 1% per annum of experience). This may be counter-intuitive, but these results are robust to the inclusion of a variety of other controls.

The correlation of age and on-farm experience can be seen in a scatter plot and a Pearson correlation statistic in Appendix Figure 1. The correlation coefficient between age and farming experience in the Pearson test is 0.52 (p-value <0.05). There is no higher correlation between age and farming experience as the data includes a significant number of people who took up farming (potentially 'lifestyle blocks') at a higher age. We estimated the same regression models without age variables (Appendix Table 8). On-farm experience still has a significant relation to drought intensity (OR = 0.994) but an insignificant one to drought frequency. Overall, we can conclude that for any additional year of on-farm experience, farmers tend to reduce their perception of drought risk in the next 50 years at only 1% or 0.6% without age controls.

The ORs of the gender variable are significantly smaller than 1 (at about 0.6), meaning that male farmers will be approximately 40% less concerned about future droughts. The education indicator's ORs are approximately 1.23 for the 6 models of drought frequency and intensity, indicating that if farmers have a bachelor's degree or more, they tend to increase their perception of drought risk in the future. The ORs of the total owned and leased area have significant results (approximately 0.9 for the 10 models), meaning that each increase in the area is likely to decrease the perception of drought risk by about 10%.

5.2. The focus on climate challenges in the next 5 years

Table 4 shows the associations of future focus in the three issues that were included in the survey: Columns (1)-(4) are "becoming more resilient to changing climate", columns (5)-(8) are "reducing greenhouse gas emission", columns (9)-(12) are "using water more efficiently." The difference between the columns in each pair is the variable measuring the perception of frequency or intensity of future drought risk[10] and drought experience. The purpose of this part is to estimate the influence of drought risk perception and drought experience on the climate-related focus of their activities.

As may be expected, both perception of drought frequency and intensity have relationships with an emphasis on actions for being more resilient to climate change, using water more efficiently, and reducing greenhouse gas emissions. In table 4, the ORs of drought frequency and intensity perception to climate resilience in models (1), (3) and (4) are 1.6, 2.2 and 1.2, respectively, indicating that when farmers perceive the increase of drought risk in the future, they tend to focus more on becoming more resilient to climate change in the next 5 years. Meanwhile, perception of drought frequency and intensity is predicted to increase future activity on reducing greenhouse gas emission (the OR are 1.75, 1.3, 1.68, and 1.23, respectively). Furthermore, if farmers perceive that drought frequency will increase in the future, they have the tendency to increase their focus on using water more efficiently (OR=1.494) but the perception of drought intensity has an insignificant result.

[10] We do not include both the frequency and intensity measures in one model because of their collinearity.

Past drought experience seems to have little association with adaptation choices once we control for drought risk perception. We estimate two types of models with different drought experience variables: one for total drought days in separate years and one for difference of drought days between 2019 and the average previous 10 years. Only drought days in 2014 have significant results for all 6 models of drought days experience, but increasing by only 0.7% and 1%. In columns (5) and (7) of "reducing greenhouse gas emission", the increase of drought days in 2010 is predicted to increase farmers' focus on greenhouse gas in the future (OR = 1.005) but drought days in 2013 and 2018 can reduce the focus level of greenhouse gas emission, at 1% and 1.7% respectively. The difference in drought days between 2019 and the average previous 10 years has a significant relation to the focus on using water (OR=0.991), representing that when drought days increase compared to the past, farmers have tendency to reduce their focus on using water more efficiently at 0.9%. Although some indicators of drought experience are statistically significant, the numbers are close to one, meaning that the drought experience in these models has no large real significance.

The ORs for age from 61-70 and +71 years old on greenhouse gas emission are significantly larger than 1 in models (5) and (7) (1.5 and 1.6, respectively), indicating that older farmers are likely to be more inclined to focus on reducing greenhouse gas emissions. However, age does not relate to their resolve to become more resilient to changing climate or using water more efficiently. Farm experience of farmers seems to have no relationship with their behaviors on climate-related focuses.

The gender of farmers has a significant association with their focus on climate resilience and water use with the ORs of 0.79 and 0.57, indicating that male farmers tend to focus less on being more resilient to climate change and using water more efficiently but there is no difference between male and female on their decisions about greenhouse gas emission reduction. More educated farmers tend to plan to focus more on all three climate challenges in the next 5 years (the ORs of education in columns (2)(4), (5)-(8), and (10) (12) are approximately 1.3 and significant).

The prediction of total drought days from 2009 to 2018 on three climate challenges can be seen more in Appendix Table 9. Insignificant results of total drought days of long-term experience indicate long-term drought experience and three climate-related adaptations have no relationship.

Table 3: **OR coefficients from ordinal logistic regression of drought perception**

Dependent variable: Perception		Drought frequency					Drought Intensity			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Drought Experience (days)										
D-days 2010	1.000					1.000				
	(0.003)					(0.003)				
D-days 2013	0.999					0.999				
	(0.004)					(0.004)				
D-days 2014	0.999					0.998				
	(0.004)					(0.004)				
D-days 2015	1.001					0.998				
	(0.005)					(0.004)				
D-days 2017	1.007					1.006				
	(0.006)					(0.006)				
D-days 2018	0.988					0.989				
	(0.008)					(0.008)				
Total D-days 2009 to 2018		1.000					1.000			
		(0.001)					(0.001)			
Total D-days 2014 to 2018			1.002					0.998		
			(0.002)					(0.002)		
Differences in D-days 2019 and average previous 10 years				1.001					1.008**	
				(0.004)					(0.004)	
Differences in D-days 2019 and average previous 10 years					1.001					1.008**
					(0.004)					(0.004)
Age (Ref: <40 years old)										
40-50	1.253	1.248	1.234	1.247	1.247	1.358	1.353	1.357	1.364	1.360
	(0.242)	(0.242)	(0.242)	(0.241)	(0.241)	(0.234)	(0.233)	(0.233)	(0.233)	(0.233)
51-60	1.499*	1.497*	1.498*	1.494*	1.491*	1.876***	1.889***	1.880***	1.882***	1.862***
	(0.245)	(0.244)	(0.234)	(0.234)	(0.234)	(0.229)	(0.228)	(0.228)	(0.228)	(0.228)
61-70	1.547*	1.566*	1.568*	1.562*	1.559*	1.893***	1.928***	1.917***	1.915***	1.898***
	(0.245)	(0.244)	(0.243)	(0.243)	(0.243)	(0.239)	(0.237)	(0.237)	(0.237)	(0.237)
70+	1.395	1.403	1.404	1.399	1.396	1.497	1.519	1.512	1.502	1.489
	(0.282)	(0.281)	(0.281)	(0.280)	(0.280)	(0.275)	(0.273)	(0.273)	(0.273)	(0.273)
On farm Experience (years)	0.992*	0.992*	0.992*	0.991*	0.991*	0.989**	0.989**	0.989**	0.989***	0.989***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Gender (1=Male)	0.596***	0.600***	0.600***	0.600***	0.600***	0.667***	0.669***	0.671***	0.670***	0.675***
	(0.114)	(0.114)	(0.114)	(0.113)	(0.113)	(0.113)	(0.112)	(0.112)	(0.112)	(0.112)
Education (1=Bachelor or more)	1.276**	1.276**	1.275**	1.276**	1.275**	1.129	1.132	1.130	1.127**	1.128**
	(0.106)	(0.106)	(0.106)	(0.106)	(0.104)	(0.105)	(0.104)	(0.104)	(0.104)	(0.104)
Log(total area) (ha)	0.900***	0.904***	0.903***	0.904***	0.930***	0.928***	0.931***	0.930***	0.930***	0.931***

	(0.028)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)
Observations			1,521							

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p<0.01$. Robust standard errors are shown in parentheses.

Table 4: **Focus on three climate challenges in the next 5 years**

	Becoming more resilient to changing climate				Reducing greenhouse gas emission				Using water more efficiently			
	(1)	(2)	(3)	4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
D-days 2010	0.998		0.998		1.005*		1.005*		1.002		1.002	
	(0.003)		(0.003)		(0.003)		(0.003)		(0.003)		(0.003)	
D-days 2013	0.998		0.998		0.990***		0.991***		0.994		0.994	
	(0.004)		(0.004)		(0.004)		(0.004)		(0.004)		(0.004)	
D-days 2014	1.008**		1.008**		1.007**		1.007**		1.010***		1.010***	
	(0.004)		(0.004)		(0.004)		(0.004)		(0.004)		(0.004)	
D-days 2015	0.994		0.994		0.997		0.997		1.004		1.004	
	(0.004)		(0.004)		(0.004)		(0.004)		(0.004)		(0.004)	
D-days 2017	1.006		1.005		0.999		0.999		0.998		0.998	
	(0.005)		(0.005)		(0.005)		(0.005)		(0.005)		(0.005)	
D-days 2018	0.986*		0.985**		0.983**		0.983**		0.989		0.989	
	(0.008)		(0.008)		(0.008)		(0.008)		(0.008)		(0.008)	
Differences in D-days 2019 and average previous 10 years		0.995		0.995		0.997		0.997		0.991**		0.991**
		(0.004)		(0.004)		(0.004)		(0.004)		(0.004)		(0.004)
Drought Frequency will increase by 2050 (=1)	1.586**	1.094			1.751***	1.282***			1.494*	0.991		
	(0.212)	(0.076)			(0.213)	(0.079)			(0.212)	(0.085)		
Drought Intensity will increase by 2050 (=1)			2.171***	1.198***			1.679***	1.225***			1.352	1.105
			(0.191)	(0.072)			(0.192)	(0.074)			(0.189)	(0.080)
Age (Ref:<40 years old)												
40-50	0.758	0.869	0.738	0.859	0.923	0.816	0.929	0.814	1.016	1.064	1.015	1.048
	(0.219)	(0.230)	(0.219)	(0.230)	(0.212)	(0.228)	(0.212)	(0.228)	(0.216)	(0.254)	(0.215)	(0.254)
51-60	0.839	1.064	0.830	1.042	1.312	0.960	1.338	0.954	1.162	1.161	1.174	1.134
	(0.211)	(0.221)	(0.212)	(0.221)	(0.204)	(0.220)	(0.204)	(0.220)	(0.208)	(0.246)	(0.208)	(0.246)
61-70	0.898	1.096	0.875	1.073	1.487*	1.005	1.505*	0.999	1.091	1.071	1.097	1.049
	(0.221)	(0.230)	(0.221)	(0.230)	(0.215)	(0.230)	(0.215)	(0.230)	(0.218)	(0.256)	(0.217)	(0.256)
71+	0.840	1.198	0.829	1.188	1.536*	1.067	1.574*	1.073	1.059	1.173	1.072	1.157
	(0.256)	(0.265)	(0.256)	(0.265)	(0.249)	(0.266)	(0.248)	(0.266)	(0.251)	(0.293)	(0.251)	(0.293)
On farm Experience	0.998	0.988***	0.998	0.989***	0.999	1.001	0.999	1.000	0.996	0.994	0.996	0.994
(years)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)	(0.005)
Gender	0.784**	0.890	0.790**	0.899	0.958	0.089	0.960	0.078	0.569***	0.956	0.569***	0.971
(1=Male)	(0.106)	(0.109)	(0.106)	(0.109)	(0.104)	(0.112)	(0.104)	(0.112)	(0.106)	(0.120)	(0.106)	(0.120)
Education	1.111	1.208*	1.098	1.207*	1.202*	1.272**	1.206*	1.286**	0.907	1.307**	0.908	1.300**
(1=Bachelor or more)	(0.098)	(0.103)	(0.098)	(0.103)	(0.096)	(0.104)	(0.096)	(0.104)	(0.097)	(0.112)	(0.097)	(0.112)
Log (total area)	1.105***	1.032	1.108***	1.034	1.113***	1.177***	1.115***	1.174***	0.865***	0.988	0.866***	0.990
	(0.026)	(0.026)	(0.026)	(0.026)	(0.025)	(0.027)	(0.025)	(0.027)	(0.026)	(0.029)	(0.026)	(0.029)

Observations	1,521

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p<0.01$. Robust standard errors are shown in parentheses

5.3. Robustness checks

If recent historical experience has a stronger influence on chosen behavior and risk preferences, then the unweighted past exposure measure we use does not fully reflect farmers' concerns. To account for such discounting, we use a weighted average of historical exposure to drought days over 12 years, with linearly declining weights using a method developed by Malmendier and Nagel (2011) and used in Aizenman and Noy (2015). The weighted average of drought days is calculated across all past years from 2007 to 2019 at a given point with weights declining with time. This index then places more weight on the recent past than on the more distant one. The formula of the weighted average of past drought days for each household i in year t can be calculated as:

$$A_{it}(\lambda) = \sum_{k=1}^{age_{it}-1} w_{it}(k,\lambda)\, R_{t-k} \qquad (3)$$

where k is how many years ago the drought was realized ($0 < k < 12$); parameter λ, which controls the shape of the weighting function; R_{t-k} is the drought days in year $t-k$. In our specification, we include drought days back to 12 years, so the ages of farmers are also back to 12 years from time t (t is the year of survey 2019). The weights $w_{it}(k,\lambda)$ are defined by:

$$w_{it}(k,\lambda) = \frac{(age_{it}-k)^{\lambda}}{\sum_{k=1}^{age_{it}-1}(age_{it}-k)^{\lambda}} \qquad (4)$$

where age_{it} is the age of farmer i at time t. In our case, age_{it} the age of farmer at the time of the survey in 2019. We assume $\lambda = 1$ (a linear weighting function)[11]. Then, we estimate the models with weighted average of past drought days, placing linearly declining droughts on more distant events. The results can be shown in Appendix Table 10; with this specification, the ORs for the weighted average of past drought days are statistically insignificant.

[11] With $\lambda > 0$, weights are decreasing in the lag k (concave for $\lambda < 1$, linear for $\lambda = 1$, and convex for $\lambda > 1$). See more the 3 cases of λ in Malmendier, U., & Nagel, S. (2011). Depression babies: do macroeconomic experiences affect risk taking? *The quarterly journal of economics*, *126*(1), 373-416.

6. Discussion and Conclusion

This study examined the perception of farmers in different areas of New Zealand with regards to drought risk and climatic change and the implications of these perceptions on climate adaptation actions that these farmers choose to pursue. The adaptation options which we examine include reducing greenhouse gas emissions, strengthening climate resilience, and using water resources more efficiently.

Drought has occurred everywhere in New Zealand at some point over the past 14 years. The North Island has been particularly affected by drought, especially the Waikato region, which is also the country's most important dairy farming region (dairy being by far the most important agricultural sector). As such, droughts have a significant impact on the overall New Zealand economy. The driest years in the time frame we examine were 2010, 2013, and 2020, with most droughts occurring in summer between December and March.

In general, farmers expect an increase in drought frequency and intensity by 2050. More than 90% of farmers believe that droughts will increase for their farms. Indeed, in the northern part of the North Island (e.g., in Auckland and Waikato), nearly all farmers perceive an increasing drought risk.

We also find that age, gender, and education are correlated with the future drought risk perception of farmers. Similar to Frumkin et al. (2012), we find that older respondents, who have experienced more drought in the past expect drought to increase in frequency and intensity more than their younger colleagues. Female farmers are more concerned about future droughts than male farmers. Moreover, if farmers have higher education, they tend to perceive more future increase in drought frequency and intensity by 2050. These findings are consistent with the finding of Deryugina (2013) from the US - that the college-educated and females are more concerned about global warming.

Importantly, drought perception of farmers is associated with their adaption choices to climate change. If farmers perceive an increase in drought risk by 2050, they will focus more on reducing greenhouse gas emissions, the climate resilience of their farms and try to improve their use of water resources.

These set of findings illustrate that age, education, gender, and total owned land all correlate with considerations of farmers about their perceptions of future drought risk. Older farmers intend to focus efforts on greenhouse gas emission reduction more than younger farmers. Farmers who have a university degree will focus more on reducing greenhouse gas emissions than farmers without a degree. Interestingly, female farmers focus more on increasing climate resilience and using water more efficiently than males. Moreover, if farmers owned or leased more land, they tend to increase their focus on all three climate challenges.

We believe that understanding drought perception, and specifically their role in determining adaptation decisions will shed some useful light that can improve policy responses to the risks of droughts in New Zealand. Finally, we note that data do not contain information about mitigation methods that farmers have been using already to deal with drought or about their efficacy. Understanding these is important to the shaping of any further policy-related adaptation to droughts, especially within the context of a changing climate. We leave these issues for further research.

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