Impact of Droughts on Farms' Financing Choices: Empirical Evidence from New Zealand

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(Manuscript received 26 December 2021, in final form 21 October 2022)

ABSTRACT: The interaction between climate change, agriculture, and financial markets is a topic that has been researched relatively little thus far. This paper intends to extend the literature by empirically testing the relationships between droughts and farms' financing choices (measured in terms of real debt and equity) in New Zealand. Using microeconomic farm-level financial records available from the tax authorities, we quantify how past droughts (measured by the New Zealand pasture growth index) impact farms' financing choices. We show a statistically significant positive impact of droughts on short-term and long-term debts, equity for dairy farms, and short-term debt for sheep and beef farms.

KEYWORDS: Drought; Climate change; Agriculture; Economic value; Regression

1. Introduction

In the age of anthropogenic climate change, countries increasingly focus on drought risks. In Aotearoa New Zealand, successive projections by the National Institute of Water and Atmospheric Research (NIWA) suggest that climate change will lead to more frequent and intense droughts in most of the main agricultural areas (National Institute of Water and Atmospheric Research 2017). Past data reveal that about 85% of New Zealand districts were affected by droughts during the period 2007–16. Droughts in a country like New Zealand, which is heavily dependent on agricultural exports, can severely affect the economy. Estimates suggest that the 2008 drought cost the national economy over USD $1.5 billion (Butcher and Ford 2009), and the 2013 drought lowered annual GDP by 0.6% (Kamber et al. 2013).

Droughts can generally lead to a reduction in agriculture production, mainly of pasture-based animal husbandry and unirrigated crop production. See, for example, evidence from Australia (Edwards et al. 2009; Tran et al. 2016) and New Zealand (Timar and Apatov 2020). But, droughts may also lead to higher farm revenue if prices go up as a consequence of the drought (Kingwell and Xayavong 2017; Pourzand et al. 2020), though Pourzand et al. (2020) also record an increase in debts as costs go up as well. Debts can help to smooth income between financially good and difficult years (Greig et al. 2019; Ma et al. 2020). Statistics from Reserve Bank of New Zealand reveal that the total farm debt has increased by 270% over the past 20 years (Reserve Bank of New Zealand 2019).

When farmers face the need to obtain additional funding, they may either borrow externally (debt) or use their resources (equity) to finance both desired consumption smoothing and necessary investments. The use of farm debt or personal equity may be an important factor during droughts. While previous research studies have explored the linkage of droughts and agricultural productivity and performance, they leave an important research question largely unanswered: Is there an association of droughts with farm financing choices (the choice between debt or equity)?

This paper attempts to answer the aforementioned question in Aotearoa New Zealand's (NZ) context by exploring the empirical relationship between droughts and farm debts and equity, using NIWA data on droughts and Statistics NZ's Longitudinal Business Database (LBD) on farms' balance sheets. The LBD contains the financial records of all farms in NZ as these have been submitted to the tax authorities. Focusing on dairy, sheep and beef farms, we argue that during or after experiencing drought conditions, farmers may face financial difficulties due to the low growth of pasture. They will then need to spend more money on animal feed or to increase their pasture production capacity. The need to fund this change can be met using internal (equity) or external (debt) sources of funds. This need can be different across dairy farms and sheep/beef farms due to their different operational processes. Dairy cows must remain healthy and alive to produce milk during or after drought seasons. In contrast, sheep/beef farms during drought seasons can be slaughtered to produce meat. This can solve the short-term liquidity crunch those farmers may be facing but can impose added longer-term challenges.

Furthermore, the sensitivity of the stock to changes in pasture conditions may be different across different types of animals. Dairy cows are considered long-term assets for dairy farms, while the animal stock for sheep/beef farms is handled as current assets in their financial records. Therefore, longer-term de-stocking challenges can be acute for dairy farms as compared with sheep/beef farms. Dairy farms can replenish their animal stock (long-term assets) through long-term financing options, while sheep/beef farms most likely require short-term financing options to replenish their animal stock in the working capital cycle.

Supplemental information related to this paper is available at the Journals Online website: https://doi.org/10.1175/WCAS-D-21-0193.s1.

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DOI: 10.1175/WCAS-D-21-0193.1

The rest of the paper is organized as follows: We first detail some of the relevant insights from the existing literature and place this paper's contribution within the existing body of knowledge. Section 3 describes our data and the models we estimate. The main results are summarized in section 4, followed by a section that concludes with thoughts about areas for future research.

2. Literature on farm balance sheets and natural hazards

Literature is scarce on the financial impact of droughts. However, some recent research has provided empirical evidence on the economic costs of droughts. For example, Huynh et al. (2020) report a significant positive correlation between drought risk and the cost of equity capital. The private debt market is also reportedly affected by droughts. Do et al. (2021) show banks charge higher loan spreads from drought-affected borrowers. Previously, Lesk et al. (2016) studies the global-scale impact of droughts on crop production and found that droughts damage the national crop production.

Prior research testing the impact of droughts on agricultural businesses has revealed some contradictory findings. For example, Edwards et al. (2009) found that droughts negatively impacted farmers' agricultural production in Australia. Lawes and Kingwell (2012) found that droughts negatively affected the business indicators they examined (business equity, operating profit/ha, return on capital, and the debt-to-income ratio), also for Australian farms. Tran et al. (2016) found that drought-affected properties earn about half as much as other "similar" properties in northern Australia. Timar and Apatov (2020) found a negative impact of droughts on dairy farms' gross output and net profit. They also recorded an unexpected reduction in intermediate expenditures of dairy farms in New Zealand against an increase in drought intensity.

In contrast, Kingwell and Xayavong (2017) demonstrated that consecutive years of drought had a significant positive effect on the operating profit per hectare and retained profit per hectare of farms in Australia. Moreover, and more recently, Pourzand et al. (2020) found that drought events have positive impacts on dairy farms' revenue and profit in the year of a drought in New Zealand.

Elsewhere, Kuwayama et al. (2019) used the U.S. Drought Monitor index, crop yields, and farm income data during the 2001–13 time period to measure the effect of droughts on farms. They found negative and statistically significant effects for each additional week of drought in dryland counties on corn and soybean yields but negligible to no effect on measures of farm income. Similarly, in Europe, Naumann et al. (2021) estimated more than 50% of total agricultural losses from adverse events can be attributed to droughts in Europe and 60% in the Mediterranean region.

Recent evidence from high-income countries has focused on the association between farm debts and farm performance (irrespective of weather shocks). For example, Ma et al. (2020) show that a higher debt ratio significantly decreases both the technical efficiency of dairy farms and their return on assets in New Zealand. They reveal the time-specific effects: A high debt ratio increased dairy productivity between 2005 and 2009, while it is associated with decreased dairy productivity between 2011 and 2014. Earlier and differing results were reported by Mugera and Nyambane (2015) for short-term and long-term debt effects on farm technical efficiency using evidence from farms in Western Australia. They found a positive association between farm technical efficiency and short-term debt, tax liability, and capital investment, but a negative association with off-farm income-generating activities. They did not find an effect of long-term debt on production efficiency and returns on assets.

The profitability of highly leveraged farms can be impacted during droughts. The evidence is supported in recent studies by Ma et al. (2020) and Godfrey et al. (2021). The findings from Ma et al. (2020) show that farm debt is significantly and negatively associated with both dairy productivity and profitability. Godfrey et al. (2021) used copula and Monte Carlo simulation techniques to estimate the financial and business risks faced by a typical wool and meat lamb enterprise in southeastern Australia. Their estimation results identify reduced profitability for farms with higher debt accumulation due to drought shocks.

Moreover, in the recent study of Pourzand et al. (2020) on farms' business indicators—income and profitability—they investigate debt-to-income ratio and interest coverage ratio. Our study is different in focusing on the financing choices of farms; that is, how farm businesses obtain funding (debt or equity). The ratio analysis, as done by Pourzand et al. (2020) is more difficult to interpret, as both the denominator and the numerator may change concurrently. We examined the determinants of the amount of debt (short term, long term, and total debt) and equity either required for operational or working capital or to acquire fixed assets like land, equipment, and machinery.

There is limited empirical evidence on the sensitivity of the financing choices of farms (their allocation of liability between debt and equity) to any change brought about during or after droughts. We attempt to pursue this line of inquiry by proposing and empirically testing the impact of droughts [as measured by the latest and improved version of the New Zealand pasture growth index (NZPGI)] on farm debt and equity.

Our decision to focus on the NZPGI follows from Pourzand et al. (2020) on some of the counterintuitive results (as discussed earlier) they found while utilizing the New Zealand drought index (NZDI) to examine the impact of droughts on farm income and profit; see Table S1 in the online supplemental material for comparison of various drought indices. They argued that the NZDI may not be designed to capture the true impact of drought on-farm operations and as such, may not account for "agricultural drought." By focusing on an index that was designed to measure pasture growth, we can turn out attention to the exact mechanism through which droughts are likely to have an impact on dairy, sheep, and beef farms—through their impact on the availability of nutritious pasture.

In the following section, we discuss the current state of drought research, the various drought measures proposed and tested in the literature, how the measure of drought we are using, the NZPGI, differs from others, and how our measure is well suited to the New Zealand context.

3. Drought measures and concepts

It remains difficult to adequately define, identify, and measure droughts due to their complex nature. Droughts are typically considered on five different dimensions: metrological, soil moisture, hydrological, socioeconomic, and environmental (Organisation for Economic Co-operation and Development 2016). All these interlinked dimensions define droughts as conditions associated with less rainfall, low levels of soil moisture, and modified water cycles (possibly due to human activities).

Agricultural droughts, a subset of the socioeconomic phenomenon, were defined by the American Meteorological Society (AMS) as "Agricultural drought links the various characteristics of meteorological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential ET, soil-water deficits, and so forth." (AMS 1997).

Mishra and Singh (2010) define a drought index as "a prime variable for assessing the effect of the drought and defining different drought parameters, like intensity, duration, severity, and spatial extent for different time scales. The monthly time scale seems to be more appropriate for monitoring the effects of a drought in situations related to agriculture." Bernknopf et al. (2018) present a better understanding of drought by using satellite missions to measure groundwater storage and soil moisture for drought monitoring. Accordingly, several different drought indices were developed in the past several decades, whose aim is typically to quantify some aspect of a drought. Table S1 in the online supplemental material summarizes some of these indices. Our preferred indicator is the NZPGI, which is calculated at gridcell level (5 km $\times$ 5 km), which allows us to accurately connect it to farms' locations. The NZ Ministry for the Environment has already identified drought as one of the major constraints to pasture grazing in New Zealand (Ministry for the Environment 2001), and our study focuses on dairy and, sheep and beef farming. These are heavily reliant on pastures, and much of that pasture is not irrigated and therefore more vulnerable to droughts. These sectors are by far the two most important sectors in NZ's agricultural production.

The NZPGI measures pasture grass growth based on radiative energy, soil moisture, and temperature potential for New Zealand's dairy regions, using data from the National Climate Station Network (NCSN). It was originally developed for use by New Zealand investors in agriculture and supported by the New Zealand Stock Exchange (New Zealand's Exchange 2019). There are two versions of the NZPGI, both developed by NIWA. The original version of the NZPGI was based on a pasture growth modeling developed in Australia. The new version of the NZPGI was improved by empirical calibration using past pasture growth data and the history of the NZPGI (Stone et al. 2019). The original version of the NZPGI assigned equal weights on measuring factors (radiative energy, soil moisture, and temperature), whereas the revised version reweighted these factors. Moreover, the new version is adjusted to match the units of pasture growth, of kilograms of dry matter per hectare per day, thus discarding the 0-to-1 index range in the older version.

The values of the NZPGI correspond to the amount of grass expected to grow in a "normal" hectare of farmland. The lower values indicate less grass growth, and the upper values indicate ideal conditions or more growth of grass. The values show a unit of kilograms of dry matter per hectare per day.

Other vegetation growth measures have provided insights into agricultural drought severity elsewhere. For example, Weier and Herring (2000) used the normalized difference vegetation index (NDVI), obtained from remote sensing (satellite) data, which considers reduced plant growth, as a drought indicator. Similarly, the NDVI was used to estimate the regional pasture growth rate in the agricultural zone of Western Australia (Hill et al. 2004).

4. The New Zealand context

a. *The agriculture sector in New Zealand*

Agriculture is an important sector in the New Zealand economy. The sector contributes 4% to its gross domestic product worth more than NZD $12 billion in 2019 (Stats NZ 2021) Dairy farming is by far the largest agricultural subsector, followed by beef and sheep farming and horticulture (New Zealand Government 2016). Agriculture, and especially dairy, is the biggest contributor to trade, constituting about 34% of New Zealand's exports worth NZD $19.7 billion, which directly added NZD $10.2 billion to the economy. In 30 years, dairy exports have grown 10 times from NZD $2 billion to almost $20 billion per year. The sheep and beef sector is delivering about NZD $8.3 billion in New Zealand's export revenue and directly added around NZD $5.8 billion to the economy (Dorigo and Ballingall 2020).

b. *Drought risks in New Zealand*

NIWA defines droughts as a deficit in rainfall, restricting human activities like farming (National Institute of Water and Atmospheric Research 2019). The Ministry for Prime Industries of New Zealand classifies droughts into three main adverse events: localized, medium scale, and large scale, based on the spatial extent and the intensity of an event and the ability to prepare and the capacity to cope with it. New Zealand's most intensive drought was in 2013. This event affected some parts of the South Island and the whole of the North Island.

New Zealand has been experiencing a change in the regional rainfall patterns over the past 50 years; these are changes associated with anthropogenic climate change. A Ministry for Environment and Statistics New Zealand report from 2017 found drier soils at 7 sites of a total of 30 sites from 1972 to 2016. Many of the most drought-prone regions are expected to see further changes in rainfall patterns and rising temperatures that will cause even more droughts (Ministry for the Environment and Stats NZ 2017). The western part of the country is predicted to experience increased rainfall during spring and winter, whereas the east and north are expected to experience decreasing trends. The west and central North Island are expected to be drier during the summer, and the east part will have increased rainfall during summer (Ministry for the Environment 2018). The glaciers of the Southern Alps have been melting and reducing the volume of ice at a rate of 11% over the period 1976–2005 (National Institute of Water and Atmospheric Research 2007b). This is also affecting the flow of water in rivers during spring and summer that have a significant consequence for irrigated farmland, especially in Canterbury.

New Zealand's most extreme recent drought was in 2013. Northland, the region at the northern end of the North Island, is the most frequently drought-affected region with four drought events affecting it from 2007 to 2017 (Mol et al. 2017). The eastern part of the Hurunui district (South Island) experienced the longest drought in recent times, during 2015/16 (Mol et al. 2017). Regional climate modeling projects an increased drought severity in most parts of the country except for the west coast and southland (in the South Island), and Taranaki-Manawatu (North Island) (Ministry for the Environment 2018).

c. Agricultural debt trends in New Zealand

The total farm debt in New Zealand is NZD $62.3 billion, which has increased by 270% over the past 20 years and counted for 14% of total bank lending (Reserve Bank of New Zealand 2021b). Agriculture sector debts are mostly associated with dairy, sheep and beef, and horticulture farming. The dairy sector accounts for 61% to total farm debts worth NZD $38.03 billion, and the sheep and beef sector accounts for 24% to total farm debts worth NZD $14.92 billion (Reserve Bank of New Zealand 2021a).

According to the economic survey of Dairy New Zealand, the term liabilities of the dairy farm debts (including personal debts) have increased by 69% from 2008/09 to 2017/18. In contrast, the average farm size has increased by only 17%. According to this survey, 24% of farmers hold more than 70% debt to asset ratio, and 4% of farmers have more than 90% debt to asset ratio (DairyNZ 2018).

5. Data and method

a. Data

We used two major sources of data for our study: NIWA for weather data and Statistics New Zealand's longitudinal business data (LBD) for financial farm-level data. The LBD is a large micro (unit record) administrative database of all New Zealand businesses, compiled by Statistics New Zealand from data obtained by other government agencies (such as the tax authorities). It has information on six major topics, including agriculture, business financial and tax information, business practices, employment, innovation, and international trade and tourism. We combined the agriculture and business financial datasets. The agricultural data are obtained from agricultural production surveys and the agricultural census starting from 2002. The average response rate of eligible units to the Agriculture Production Surveys is 84% (2002–18). These respondents produce 87% of the estimated total agricultural output, on average (Stats NZ 2020). The business financial data are obtained from the IR10 financial statement summary form submitted annually to New Zealand Inland Revenue (IRD) for the processing of tax returns by all businesses.

For weather data, we use the latest version of NZPGI (see section 3 for details). It is available daily since 1972. We used the NZPGI to identify the drought conditions by defining three thresholds combining the duration and intensity of the drought. If the $20 \leq \text{NZPGI} \leq 30$ for consecutively 10–20 days, it is presumed to have been a mild drought. If the $\text{NZPGI} \leq 20$ for consecutively 20 or more days, it is identified as a severe drought. We only examined data for the summer season from December to April to identify drought occurrences, since droughts generally do not occur in the rest of the year, nor are they economically meaningful given the agricultural crop cycle in the country during winter. The NZPGI data are available from 11 491 nodes of the virtual climate station network (VCSN)—which is an approximately 5-km grid covering the whole of New Zealand.

b. Sample construction and variables

The LBD sample we analyze includes all businesses identified on Statistics New Zealand's Business Frame as engaging in dairy farming and/or sheep and beef farming. We used agricultural industry ANZIC06/ANZIC96 codes to identify our sample population at the enterprise level from the Agricultural Production Survey/Census (APS/C) in LBD for the year 2002–18. We used the same APS/C to identify each farm's geographical location at the meshblock level.[1] These unit records were also linked to each farm's financial tax data (Form IR10). We used the tax data to extract information about each farm's debt, its maturity, and other balance sheet variables.

For the NZPGI, we had a daily dataset from 11 491 VCSN grids covering the whole country. Each farm was assumed to be located in the centroid of its respective meshblock and was then linked to the records from its nearest VCSN grid point (see Fig. S5 in the online supplemental material). We used the set of variables described in Table S2 in the online supplemental material as financing choices measures and drought measures to address our research questions.

c. Empirical specification

We pursued a microeconometric approach to study the effects of drought on farm debts and equity that is almost similar to those used by Pourzand et al. (2020) and Timar and Apatov (2020). We used fixed-effect annual panel regressions for pasture-based dairy and sheep/beef farming from 2002 to 2018. Various measures of farm debt are our dependent variables, whereas the recording of the occurrence of droughts and their intensities are our primary independent variables. Droughts may have lasting effects on farm debts or equity, so we included lags of up to 2 years for the NZPGI-derived measures of droughts. The models that we estimate are

$$\text{model 1:}\quad Y_{it} = \alpha + \delta_0 D_{it} + \delta_1 D_{i,t-1} + \delta_2 D_{i,t-2} + c_i + u_{it} \quad \text{and} \tag{1}$$

$$\text{model 2:}\quad Y_{it} = \alpha + \delta_0 D_{it} + \delta_1 D_{i,t-1} + \delta_2 D_{i,t-2} + \delta_3 \text{CD}_{it} + c_i + u_{it}, \tag{2}$$

[1] Meshblocks are the smallest geographical unit for which data are reported by Statistics NZ. In 2018, there were more than 50 000 meshblocks in New Zealand.

where Y_{it} is the farm financing choices measures—real short-term debt, real long-term debt, real total debt, farm equity, and related financial measures (profit, and interest payments)—of farm i at time t; D_{it} is the binary variable indicating drought conditions computed through NZPGI for farm i at time t, using the thresholds described above; the farm fixed effects c_i accounts for any unobserved and time-invariant farm heterogeneity that may influence farm debts and may be correlated with current and past drought conditions; u_{it} is an independent and identically distributed (iid) error term representing unobserved factors that change over time and affect Y_{it}.

In our model 2, we add a variable CD_{it} that measures if there were consecutive droughts (over more than one summer season). The hypothesis that we implicitly test here is that consecutive droughts imply a bigger financial hit to farms than those that are separated by "good" years; that is, a farm's balance sheet is more vulnerable to drought if the farm is entering it had been weakened already by a drought episode the year before.

In comparison with Pourzand et al. (2020) and Timar and Apatov (2020), we did not include time-fixed effects in our model as there is a significant temporal correlation between droughts in different regions in NZ. As such, including time effects will only test the importance of droughts hitting a specific region relative to, or more than, the average burden of droughts in the rest of the country in that year/summer.[2] We also used our model for other farm financial measures (real total equity, real total profit, and real interest payments). We checked for these financial measures to find how the financing choices are changed to meet the financial challenges of farmers during or after drought.

We further stratified our sample into farm sizes based on their total land to evaluate whether the effects of droughts on balance sheets and the financing choices varied across different farm sizes. A farm is categorized as small if its total land area is less than 100 ha and medium if the total land area is between 100 and 300 ha. Large farms are those with a land area larger than 300 ha. The financial data are converted to real dollar values by using the GDP implicit price deflator.[3] We winsorized the data at 1%.

6. Results

a. Pasture drought statistics

The New Zealand pasture growth index frequency distribution is shown in Fig. S1 in the online supplemental material. The average value of the index lies between 40 and 60. The index value remained below 100 in our study period, indicating maximal conditions for pasture growth. Figure S2 in the online supplemental material identifies the occurrence of droughts, as defined by the thresholds described previously.

In 2013, a maximum of 81% of the total grid stations of New Zealand indicated drought conditions, and 12% showed severe drought conditions as shown in Fig. 1.

In Fig. S3 in the online supplemental material, we combined the grid station data into district boundaries for each year and identify the top 10 districts experiencing drought conditions. Southland district is the area hit by drought conditions most frequently from 1997 to 2018. Central Otago and Marlborough are most hit by severe drought conditions for the same period. In Fig. S4 in the online supplemental material, we identified the number of districts that experienced drought conditions at more than 50% of their grid stations. In 2013 and 2015, most of the districts experienced these drought conditions. The Hurunui district shows drought conditions at all its grid stations in 2015 and 2016.

b. Debt statistics

Table 1 describes the statistics for our dataset across all farms and Table S3 in the online supplemental material describes the statistics by different farm sizes.

On average, dairy farming is associated with higher real short-term, long-term, and total debt than sheep/beef farming. Similarly, the equity, profit, and interest payments are higher for dairy farms as compared with sheep/beef farms. Dairy farms are, on average, more leveraged than sheep/beef farms. Dairy farms hold 45% debt and 55% equity, on average, whereas the financing choices of sheep/beef farms consist of 24% debt and 76% equity. On average, interest payments are greater than profits for dairy farms signals more financial fragility for at least some dairy farms, whereas the opposite is true for sheep/beef farms.

Small farms hold more equity than debt on average for both dairy and sheep/beef farms. These smaller entities are less reliant on external sources of funds. By contrast, medium-size farms hold an approximately equal share of debt and equity, on average, and large farms use more debt than equity in their financing choices, for the dairy sector. The sheep and beef farms largely hold the same low-leveraged financing choices for different farm sizes.

c. Regression estimates

We estimate our main equation for financing choices variables as debt and equity measures at two different intensities of droughts from mild to severe and both. The debt measures include real short-term debt, real long-term debt, and real total debt, and other measures include total equity, total profit, and cost of debt as interest paid. We estimated our model for the full sample and subsamples categorized by farm sizes. In model 1, we did not include the variable denoting consecutive drought seasons, whereas, in model 2, we used both time-lagged drought indicators and the consecutive drought indicator. The estimation results for all measures for dairy farming and sheep and beef farming are discussed separately in the following sections.

[2] We tested and found a statistically significant autocorrelation in the residuals. To address this issue, according to Hoechle (2007), Petersen (2009), and Thompson (2011), we used robust clustered standard errors. Further discussions on autocorrelation and alternative model test results are presented in the online supplemental material (along with Tables S44–S47). We took guidance from Kitsios et al. (2022) to test our alternative model.

[3] GDP implicit deflator shows the rate of price change in the economy as a whole measured as nominal GDP divided by real GDP and multiplied by 100.

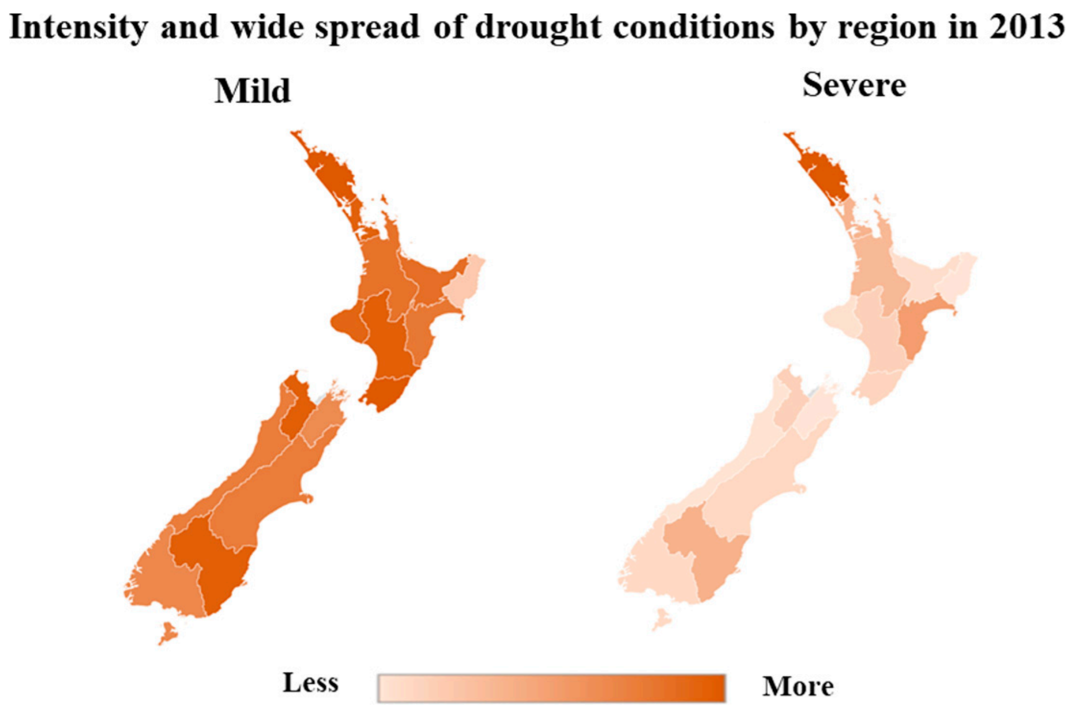

FIG. 1. The intensity of drought conditions identified by the percentage of drought-affected NCSN stations within each region. These range from 0% to 100% of grids for mild and from 0% to 63% for severe.

d. Debt measure results

The regression results of the impacts of different drought conditions on debt for all dairy farming are shown in Table 2. The results show a positive and significant impact of all drought conditions on the real short-term debt contemporaneously ($p < 0.05$). The positive impact for the next two years after the drought [$\delta_{\text{Drought}(t-1)} = 50.28$, $p < 0.05$, and $\delta_{\text{Drought}(t-2)} = 86.31$, $p < 0.01$] on real short-term debt of dairy farms was stronger than the positive impact for contemporaneous drought [$\delta_{\text{Drought}(t)} = 33$, $p < 0.05$]. The same results were found for long-term and total debt. It indicates that dairy farmers borrow more money after drought conditions.

When we separated the drought measure into mild and severe drought, the findings highlighted the estimated coefficients during the severe droughts were statistically insignificant for short-term debt[4] [$\delta_{\text{Drought}(t)} = 46.52$, $p > 0.10$], whereas the estimated coefficient of the long-term debt is positive and statistically significant [$\delta_{\text{Drought}(t)} = 186.26$, $p < 0.01$], implying dairy farmers are relying more on long-term borrowings during severe droughts. The regression results for total debt for dairy farming are commensurate with the results for short- and long-term debts; for both mild and severe drought conditions, and for all time lags. The results remain consistent when we controlled for consecutive droughts in model 2. These estimated results suggest that droughts increased the debt of dairy farmers ranging from NZD $33,000 to NZD $326,850.

Tables S4–S6 in the online supplemental material present the results for all forms of debts at different dairy farm sizes. These results show that small and especially medium-size farms experience an increase in short-term debt in the aftermath of droughts. Medium-size farms see a higher increase in their debt levels than do small farms, and the increase is larger for more severe droughts, though there are less consistent results for the contemporaneous impact of the droughts. However, at the first lag ($t - 1$) and second lag ($t - 2$), the impact for the medium-size farm is statistically significant and for small-size farms, the results are statistically significant at the second lag ($t - 2$) under severe drought conditions. The medium-sized farms show a slight increase in short-term debt if previously experienced drought season and are now under severe drought. We have not found any statistically significant impact on short-term debt for large farms under any drought intensity at any time. It appears that large farms can weather drought conditions (even more severe ones) without much additional short-term borrowing, in contrast with small and medium-sized farms. We have also not recorded any statistically significant impact of droughts on the long-term debt of large farms. The medium-size farms do accumulate more long-term debt in the two years following the drought, and with some evidence of a delayed accumulation of debt after two years, for large farms. The results for total debt remain mostly consistent for small-size and medium-size farms, and we have not found any statistical significance impact for large-size farms.

[4] Possibly, this result arises because dairy prices increase during severe droughts, because these are more widespread and hit many more farms concurrently.

TABLE 1. Descriptive statistics by industry across all farms. All of the values of mean and standard deviation (SD) are in thousands of NZD (real terms) except for the farmland size, which is in hectares. Data source: Statistics NZ.

Variables	Dairy farming Obs	No. of farms	Mean	SD	Sheep and beef farming Obs	No. of farms	Mean	SD
Short-term debt	26 142	1746	403	1324	27 690	1863	111	504
Long-term debt	26 142	1746	1750	4183	27 690	1863	240	1536
Total debt	26 142	1746	2167	4774	27 690	1863	357	1796
Total equity	26 142	1746	2604	7528	27 690	1863	1111	6378
Total profit	26 142	1746	96	263	27 690	1863	29	218
Interest paid	26 142	1746	120	266	27 690	1863	16	83
Farmland	25 665	1743	183.6	176.99	27 237	1857	266.7	1293.03

Furthermore, our results show an additional increase in debt levels associated with consecutive drought seasons. The medium-sized farms are more affected than small farms and impacts are larger for them under severe drought conditions.

Table 3 presents the equivalent results for sheep and beef farms for the same dependent variables as in Table 2. The results show the statistically significant positive impact of drought on short-term debt for the full sample. The estimated coefficients, however, are smaller than for the dairy farms and statistically significant. Furthermore, the regression results show no statistically significant impact of droughts on long-term debt. These estimated results suggest that droughts increased the short-term debt of sheep and beef farmers ranging from NZD $9,620 to NZD $44,960.

The regression results for all forms of debts at different farm size levels of sheep/beef farming are presented in Tables S7–S9 in the online supplemental material. The impact is statistically significant for large-size farms only, indicating that the large sheep and beef farmers remain active short-term borrowers during and after different levels of drought conditions, but that smaller producers seem to access the debt market less. There is some evidence, however, of an increase in long-term debt for small and large sheep/beef farmers if they experience more than one consecutive drought season. One possible reason for the less statistically significant impact of droughts on debt in the sheep and beef industry may be the selling of stock as a coping strategy (Timar and Apatov 2020).

The sheep and beef farmers did not show any statistically significant impact of all and mild drought conditions on total

TABLE 2. Regression results for debt of dairy farming (1000s of NZD). Here, one, two, and three asterisks indicate significance levels of $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively. Robust standard errors clustered at farm level are in parentheses. Data source: Statistics NZ.

Indicators	Short-term debt		Long-term debt		Total debt	
Model	1	2	1	2	1	2
All droughts (NZPGI ≤ 30 and consecutive days ≥ 10)						
Drought (t)	33.00** (16.67)	32.60* (16.96)	59.31** (27.73)	68.06** (28.14)	76.66** (34.59)	84.77** (34.84)
Drought ($t-1$)	50.28** (20.14)	49.92** (20.09)	67.02** (31.49)	74.87** (31.78)	106.54*** (39.06)	113.81*** (39.00)
Drought ($t-2$)	86.31*** (15.61)	85.99*** (15.42)	133.91*** (42.11)	140.99*** (42.00)	213.36*** (43.10)	219.92*** (42.83)
Consecutive drought		−0.64 (3.56)		14.01*** (4.98)		12.98** (5.67)
Obs	26 142	26 142	26 142	26 142	26 142	26 142
Adjusted R square	0.4341	0.4341	0.7811	0.7812	0.7911	0.7911
Mild droughts (NZPGI ≤ 30 and consecutive days ≥ 10) excluding severe drought						
Drought (t)	30.72* (17.50)	28.67 (17.87)	44.90 (30.94)	54.97* (31.48)	61.53 (38.03)	69.26* (38.41)
Drought ($t-1$)	54.92** (21.53)	52.55** (21.55)	72.31** (33.12)	83.95** (33.76)	117.10*** (41.91)	126.02*** (42.01)
Drought ($t-2$)	86.06*** (16.39)	84.25*** (16.16)	131.17*** (48.67)	140.04*** (48.57)	209.85*** (49.53)	216.66*** (49.24)
Consecutive drought		−3.06 (3.61)		15.03*** (5.48)		11.53* (6.14)
Obs	24 111	24 111	24 111	24 111	24 111	24 111
Adjusted R square	0.3978	0.3978	0.7756	0.7757	0.7859	0.786
Severe droughts (NZPGI ≤ 30 and consecutive days ≥ 10) excluding mild drought						
Drought (t)	46.52 (28.78)	47.56 (28.92)	186.26*** (70.50)	158.49** (71.05)	200.42** (86.28)	174.78** (87.15)
Drought ($t-1$)	80.83*** (31.00)	78.49** (30.83)	91.29*** (32.19)	153.35*** (34.99)	149.95*** (45.80)	207.24*** (46.78)
Drought ($t-2$)	104.59*** (19.19)	102.97*** (19.90)	188.94*** (47.00)	231.96*** (48.06)	287.14*** (53.20)	326.85*** (54.87)
Consecutive drought		−1.04 (3.03)		27.69*** (6.30)		25.56*** (6.72)
Obs	16 980	16 980	16 980	16 980	16 980	16 980
Adjusted R square	0.4351	0.435	0.8193	0.8196	0.8249	0.8251

TABLE 3. Regression results for debt of sheep/beef farming (1000s of NZD). Here, one, two, and three asterisks indicate significance levels of $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively. Robust standard errors clustered at farm level are in parentheses. Data source: Statistics NZ.

Indicators	Short-term debt		Long-term debt		Total debt	
Model	1	2	1	2	1	2
All droughts (NZPGI ≤ 30 and consecutive days ≥ 10)						
Drought (t)	13.57*** (3.99)	14.54*** (4.02)	2.15 (4.72)	6.49 (4.91)	11.40* (6.91)	16.84** (6.95)
Drought (t − 1)	14.41*** (5.52)	15.36*** (5.71)	−0.43 (5.88)	3.77 (5.81)	9.86 (8.37)	15.13* (8.36)
Drought (t − 2)	15.40*** (5.71)	16.07*** (5.73)	−1.73 (5.88)	1.24 (5.82)	10.05 (8.66)	13.77 (8.61)
Consecutive drought		1.84 (1.22)		8.20** (3.46)		10.29*** (3.58)
Obs	27 690	27 690	27 690	27 690	27 690	27 690
Adjusted R square	0.565	0.5651	0.9034	0.9036	0.8697	0.8698
Mild droughts (NZPGI ≤ 30 and consecutive days ≥ 10) excluding severe drought						
Drought (t)	11.72** (4.59)	12.57*** (4.61)	0.81 (4.92)	5.35 (4.94)	8.48 (7.50)	14.07* (7.43)
Drought (t − 1)	15.08*** (5.17)	16.15*** (5.49)	−1.38 (6.03)	4.33 (5.79)	9.47 (8.40)	16.51** (8.35)
Drought (t − 2)	17.43*** (5.57)	18.13*** (5.69)	−2.66 (6.06)	1.05 (5.87)	10.80 (8.71)	15.38* (8.61)
Consecutive drought		1.47 (1.27)		7.80** (3.02)		9.62*** (3.27)
Obs	25 560	25 560	25 560	25 560	25 560	25 560
Adjusted R square	0.4873	0.4874	0.9111	0.9112	0.8719	0.8721
Severe droughts (NZPGI ≤ 30 and consecutive days ≥ 10) excluding mild drought						
Drought (t)	30.19*** (9.53)	29.59*** (9.67)	19.06 (14.31)	8.32 (14.66)	44.96*** (16.56)	34.04** (17.12)
Drought (t − 1)	9.59* (4.96)	10.66* (5.91)	−6.40 (6.66)	12.56 (8.46)	−2.47 (8.93)	16.81 (11.26)
Drought (t − 2)	15.37*** (5.57)	16.06*** (5.76)	−7.92 (6.88)	4.27 (7.18)	−0.77 (11.14)	11.63 (11.79)
Consecutive drought		0.50 (1.40)		8.83** (3.95)		8.98** (4.31)
Obs	17 244	17 244	17 244	17 244	17 244	17 244
Adjusted R square	0.7313	0.7313	0.6032	0.6039	0.5982	0.5985

debts for small-size farms and medium-size farms. The large-size farms show a statistically significant positive impact on total debt during droughts and severe drought conditions under model 1 and increased coefficient values and statistically significant impact during and after droughts in the model 2.

e. Results for equity and other financial variables

We have found statistically significant use of debt during and in the aftermath of droughts. We further examine the evolution of the alternative source of capital—equity—and also profitability, and cost of funding. The equity is tested to analyze the farmers' use of their own financial resources, as an alternative to borrowing, during or after droughts. The estimation results of these variables for dairy farming, and sheep and beef farming are shown in Tables 4 and 5, respectively.

Table 4 shows a positive and statistically significant increase in equity for dairy farms. The estimated coefficient values of the contemporaneous increase in equity are higher than the increase in total debt for dairy farmers. At first, then, the dairy farmers start investing their own resources to meet the drought challenge. But their reliance on external debt funding increases later more than their equity investments. During and after severe droughts, we found larger positive coefficients for both equity and debts. Maybe not surprisingly, we found that dairy farmers are more in need of both equity and debt funding after severe drought conditions and that they utilize both funding options.

To examine whether the need for additional funding is partly, at least, a result of declining profits, we estimated coefficients for specifications examining the correlates of real profit as the dependent variable. Coefficients for the drought measure, at all lags, are negative and statistically significant. This is noteworthy, because, in comparison with findings by Pourzand et al. (2020) who found a positive correlation with their drought measure, we found a negative impact of droughts (as measured by the NZPGI) on dairy farms' profitability.

We also find evidence of a positive effect of droughts on the interest costs of debts for dairy, suggesting an increase in debts increases the interest payments and is one of the reasons profits are lower postdrought.

Tables S10–S12 in the online supplemental material present the results for equity, profitability, and cost of funds at different farm sizes. The estimated coefficients for the equity for small-size dairy farming at all time lags are positive and statistically significant. The medium-sized farms invest more in equity if they experienced severe and consecutive droughts, and we found no statistically significant impact of droughts on large dairy farms' equity.

The results of real profit as a dependent variable remain consistent for all size farm categories, the intensity of drought, and the continuous occurrence of drought seasons. Profits universally decrease. While for the small- and medium-sized farms we find a statistically significant increase in interest payments, the large farms are not increasing their borrowing during and after droughts same, so there is also no statistically significant evidence for any change in their interest payments.

Table 5 provides the equivalent estimation of equity, profitability, and cost of funds for sheep/beef farming. We did not find

TABLE 4. Regression results for other financials of dairy farming (1000s of NZD). Here, one, two, and three asterisks indicate significance levels of $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively. Robust standard errors clustered at farm level are in parentheses. Data source: Statistics NZ.

Indicators	Total equity		Total profit		Total interest	
Model	1	2	1	2	1	2
All droughts (NZPGI ≤ 30 and consecutive days ≥ 10)						
Drought (t)	147.43*** (44.01)	162.22*** (45.07)	−21.72*** (3.71)	−22.82*** (3.72)	4.59** (2.05)	5.48*** (2.04)
Drought ($t-1$)	172.39** (75.06)	185.66** (74.79)	−8.69*** (3.29)	−9.67*** (3.30)	0.72 (3.21)	1.51 (3.19)
Drought ($t-2$)	136.96*** (45.67)	148.94*** (46.34)	−35.59*** (4.09)	−36.48*** (4.10)	7.96** (3.42)	8.68** (3.37)
Consecutive drought		23.68*** (7.39)		−1.76*** (0.54)		1.43*** (0.37)
Obs	26 142	26 142	26 142	26 142	26 142	26 142
Adjusted R square	0.8007	0.8007	0.2535	0.2537	0.7365	0.7367
Mild droughts (NZPGI ≤ 30 and consecutive days ≥ 10) excluding severe drought						
Drought (t)	134.17*** (44.17)	150.70*** (45.22)	−23.65*** (3.97)	−25.06*** (3.98)	4.23** (2.12)	5.30** (2.12)
Drought ($t-1$)	216.58** (80.49)	235.67*** (80.06)	−8.38** (3.50)	−10.00*** (3.52)	0.60 (3.41)	1.84 (3.40)
Drought ($t-2$)	134.87** (52.52)	149.42*** (53.37)	−32.59*** (4.30)	−33.83*** (4.31)	8.16** (3.84)	9.10** (3.79)
Consecutive drought		24.66*** (7.16)		−2.10*** (0.50)		1.60*** (0.41)
Obs	24 111	24 111	24 111	24 111	24 111	24 111
Adjusted R square	0.7996	0.7997	0.2563	0.2567	0.7285	0.7287
Severe droughts (NZPGI ≤ 30 and consecutive days ≥ 10) excluding mild drought						
Drought (t)	217.79** (93.99)	173.64* (94.70)	−23.84*** (7.65)	−21.92*** (7.64)	8.50* (4.37)	6.41 (4.45)
Drought ($t-1$)	197.78* (101.19)	296.44*** (102.49)	−20.91*** (5.00)	−25.20*** (5.17)	2.79 (3.40)	7.47** (3.43)
Drought ($t-2$)	269.25*** (58.65)	337.64*** (60.47)	−33.40*** (5.04)	−36.38*** (5.21)	7.54** (3.53)	10.78*** (3.55)
Consecutive drought		44.03*** (7.61)		−1.91*** (0.72)		2.09*** (0.47)
Obs	16 980	16 980	16 980	16 980	16 980	16 980
Adjusted R square	0.7987	0.7989	0.2737	0.2741	0.7878	0.7883

any statistically significant impact of droughts on sheep/beef farmers' equity concurrently, and for the first lag, whereas, for the second lag ($t-2$), there is a statistically significant increase in equity. The results of profitability for sheep/beef farming show no statistically significant impact of droughts. However, there is a statistically significant reduction in profits during severe drought conditions. There is no statistically significant impact of droughts found on sheep/beef farms' cost of debt.

The regression results for equity, profitability and cost of funds at different farm sizes of sheep/beef farms are presented in Tables S13–S15 in the online supplemental material. We found a statistically significant impact of droughts on small-sized sheep/beef farmers' equity at the second lag ($t-2$), and a statistically significant increase in equity of small and medium farms for severe and consecutive droughts. Similar to large dairy farmers, we did not find any statistical significance impact of droughts on the equity of large sheep/beef farms. However, there is a statistically significant reduction in profits during severe drought conditions for large sheep/beef farms. The statistically significant impact of severe droughts on small, medium, and large farms' profitability remains consistent as we control for consecutive drought seasons. There is no statistically significant impact of droughts found on sheep/beef farmers' cost of debt.

f. Robustness

We used an alternative set of soil moisture-based drought indicators to run regressions and test whether our results are sensitive to the use of specific drought measures. We used daily potential evapotranspiration deficit (PED) data from 11 491 VCSN (~5 km) grids covering the whole of New Zealand from the year 2000 to 2020. PED has measured the gap between water demand and the actual availability of water in millimeters. The meteorologists consider PED a useful means of ranking the severity of dry periods (National Institute of Water and Atmospheric Research 2007a). We used the thresholds of PED to identify the intensity of drought conditions based on a rule of thumb defined by NIWA—an accumulation of 30 mm more PED corresponds to an extra week of reduced grass growth (Mol et al. 2017; National Institute of Water and Atmospheric Research 2007a). Therefore, we accumulated the PED from December to April to identify the severity of the dry period each year. The drought is identified if cumulative PED ≥ 250 mm, the mild drought conditions are identified if cumulative 250 ≤ PED ≤ 320 mm, and the severe drought occurs if cumulative PED > 320 mm. The regression results for both dairy and sheep/beef farming for debt and nondebt measures are summarized in Tables S16–S19 in the online supplemental material.

We found almost similar results to the prior findings, the coefficients in the robustness test model represent similar signs and statistical significance. Our results appear robust to this alternative drought measure. We worked with the inclusion of a control variable in our model also, such as farm size. The new results are present in Tables S20–S27 in the online supplemental material. Our results remain consistent through controlling farm size in our model.

TABLE 5. Regression results for other financials of sheep/beef farming (1000s of NZD). Here, one, two, and three asterisks indicate significance levels of $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively. Robust standard errors clustered at farm level are in parentheses. Data source: Statistics NZ.

Indicators	Total equity		Total profit		Total interest	
Model	1	2	1	2	1	2
All droughts (NZPGI ≤ 30 and consecutive days ≥ 10)						
Drought (t)	30.87 (31.50)	34.63 (30.01)	1.12 (5.26)	0.87 (5.11)	0.21 (0.26)	0.32 (0.29)
Drought ($t-1$)	27.46 (41.52)	31.11 (40.38)	1.43 (1.73)	1.19 (1.61)	−0.16 (0.29)	−0.05 (0.31)
Drought ($t-2$)	83.42** (37.75)	86.00** (36.46)	0.93 (2.29)	0.76 (2.20)	−0.13 (0.28)	−0.05 (0.29)
Consecutive drought		7.12 (6.36)		−0.47 (0.50)		0.20 (0.19)
Obs	27 690	27 690	27 690	27 690	27 690	27 690
Adjusted R square	0.901	0.901	0.2023	0.2023	0.8852	0.8853
Mild droughts (NZPGI ≤ 30 and consecutive days ≥ 10) excluding severe drought						
Drought (t)	31.10 (33.50)	34.94 (31.70)	2.23 (5.53)	1.86 (5.35)	0.18 (0.26)	0.31 (0.28)
Drought ($t-1$)	29.31 (44.07)	34.14 (42.48)	2.23 (1.89)	1.78 (1.74)	−0.30 (0.28)	−0.14 (0.30)
Drought ($t-2$)	92.17** (40.49)	95.31** (38.71)	1.86 (2.25)	1.57 (2.10)	−0.12 (0.28)	−0.02 (0.28)
Consecutive drought		6.60 (6.16)		−0.63 (0.51)		0.22 (0.15)
Obs	25 560	25 560	25 560	25 560	25 560	25 560
Adjusted R square	0.9014	0.9014	0.2282	0.2282	0.8974	0.8975
Severe droughts (NZPGI ≤ 30 and consecutive days ≥ 10) excluding mild drought						
Drought (t)	−25.65 (30.27)	−51.03 (30.45)	−13.94*** (3.66)	−14.24*** (3.60)	1.13 (0.83)	0.90 (0.86)
Drought ($t-1$)	99.40 (74.24)	144.21* (74.39)	6.43 (4.98)	6.96 (5.10)	−0.41 (0.32)	0.01 (0.57)
Drought ($t-2$)	92.40* (48.26)	121.22** (48.26)	−1.78 (2.85)	−1.43 (3.16)	−0.19 (0.37)	0.08 (0.47)
Consecutive drought		20.86*** (5.82)		0.25 (0.54)		0.19 (0.23)
Obs	17 244	17 244	17 244	17 244	17 244	17 244
Adjusted R square	0.6793	0.6795	0.1282	0.1282	0.7617	0.7618

Further, we also tested our model using NZDI. The daily data for NZDI were available from the year 2007 to 2018 at the district level. We found mixed results as compared with our original results. The results are presented in Tables S28–S43 in the online supplemental material. This to some extent is in line with Pourzand et al. (2020) results and indicates that our measure of NZPGI maybe more suitable for the measurement of the challenges that droughts pose to the dairy and sheep/beef sectors in New Zealand.

7. Conclusions

This paper empirically examined the impacts of droughts, measured using NZPGI in New Zealand, on pasture-reliant farms' debts and equity. We used dairy, and sheep/beef farms' financial unit records for 17 years to identify changes in their financing choices. We investigated if the farms' borrowings, use of equity funding, and associated costs to these sources change during or after drought conditions. Our results show a statistically significant increase in short-term and long-term debts, equity, and the cost of debt for dairy farming in the aftermath of droughts, whereas the results show a statistically significant negative impact of droughts on the profitability of dairy farming. Furthermore, the occurrence of consecutive droughts increases their impact on farms' financing choices. These results show that dairy farms face more financial strain during and after droughts and need to rely on both equity and debt financing.

In comparison, our results show a statistically significant increase of only short-term debt for sheep and beef farms after droughts, and a negative impact of only severe drought conditions on the profitability of sheep and beef farms. It seems that sheep/beef farms face fewer financial challenges during and after drought conditions, possibly because they are significantly less leveraged. The results by farm size categories show that it is the small dairy farms that rely more on equity funding and short-term borrowing during and after drought conditions. Large dairy farms appear financially more resilient to drought conditions.

In comparison with dairy farms, the large sheep/beef farms remain active borrowers during and after different levels of drought conditions. They also face a reduction in profitability during severe drought conditions, whereas the small sheep/beef farmers invest more after a drought.

We tested one link in the chain from droughts to financial fragility. We examined the link from droughts to an increase in equity/debts in a potential causal chain of droughts, debts and productivity/performance, and then systemic lenders (banks) fragility. Future research may empirically explore the next stages in this causal from debt/equity to farm financial performance and banking sector profitability; as in most cases, it is banks that are the main source of lending for farms, in New Zealand and elsewhere.

Of course, all of this research is relevant to our concerns about climate change modifying the likelihoods, durations and intensities of droughts as they are experienced in New Zealand. However, there is a lot of uncertainty in our knowledge with respect to the onset and duration of droughts in general, and the impact climate change will have on these processes. The Intergovernmental Panel on Climate Change projects an intensification of the hydrological cycle, with more precipitation-related extremes (both extreme wet and extreme dry events). As such, we do not try and project the implications of our estimations for future impacts of climate change on farms' financing choices through the drought channel. We leave these efforts for future research.

Acknowledgments. We acknowledge Dr. Daithi Stone and Dr. Abha Sood Climate Scientists from the National Institute of Water and Atmospheric Research Ltd. (NIWA) for the provision of data (NZPGI and PED) used for drought identification and their useful advice.

Data availability statement. The drought data of NZPGI and PED are provided by Dr. Daithi Stone and Dr. Abha Sood Climate Scientists from the National Institute of Water and Atmospheric Research Ltd. (NIWA). We are restricted from sharing this data without their consent (Daithi.Stone@niwa.co.nz; Abha.Sood@niwa.co.nz). Disclaimer for the output produced from Stats NZ surveys: Access to the data used in this study was provided by Stats NZ under conditions designed to give effect to the security and confidentiality provisions of the Statistics Act 1975. The results presented in this study are the work of the author, not Stats NZ or individual data suppliers. Disclaimer for the output produced from the IDI and/or LBD: These results are not official statistics. They have been created for research purposes from the Integrated Data Infrastructure (IDI) and/or Longitudinal Business Database (LBD), which are carefully managed by Stats NZ. For more information about the IDI and/or LBD, please visit https://www.stats.govt.nz/integrated-data/. Disclaimer for Inland Revenue tax data: The results are based in part on tax data supplied by Inland Revenue to Stats NZ under the Tax Administration Act 1994 for statistical purposes. Any discussion of data limitations or weaknesses is in the context of using the IDI for statistical purposes and is not related to the data's ability to support Inland Revenue's core operational requirements.

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