Temporal trends in home-grown forage eaten on New Zealand dairy farms

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Abstract

Pasture is the main source of feed on New Zealand dairy farms, having the benefit of a low cost of production, giving New Zealand's dairy industry a competitive cost advantage in international markets. Previous literature indicates a plateau in forage grown and consumed on-farm (referred to as pasture and crop eaten) over the last 20 years. Farm-level performance data over 14 years from DairyBase across Northland, Waikato, Canterbury and Otago were used to analyse the medium-term trends of pasture and crop eaten at the middle (median) and top (frontier) portions of the distributions of pasture and crop eaten. A performance metric was designed to compare the time trends between top-, average- and bottom-performing farms at the national level. The results were consistent with prior literature with no substantial evidence of an increasing trend in pasture and crop eaten across any region. Furthermore, the results showed that at a national level, top-performing farms were not improving on their pasture and crop eaten, while the average- and bottom-performing farms are improving slightly. The lack of a consistent positive trend is concerning for the dairy sector's international competitiveness, making further research into new pastoral technologies and techniques paramount for maintaining New Zealand's competitive position.

Keywords: farm data, farm performance, pasture and crop eaten, quantiles

Introduction

Pasture is the main source of feed used by New Zealand dairy farmers to meet cow feed demand. In the last 10 years, the dairy sector has sourced at least 80% of their cows' diet from home-grown pasture and crops (largely forage crops grazed *in situ*) (DairyNZ 2019), known as pasture and crop eaten (PCE). Pasture has a lower cost of production compared to alternative feeds, so maximising pasture utilisation to satisfy feed demand is a key objective for farmers looking to ensure profitability (Neal & Roche 2020). The variability in PCE within and across years can affect farm profitability for that year significantly; it contributes the highest level of explanatory power among drivers of profit per hectare and return on capital (Beca 2020). Understanding how regional- and farm-level PCE changes over time is critical in determining whether New Zealand's dairy industry can maintain profitability and its competitive position in international markets.

Typically, the assessment of aggregate PCE considers the average of the distribution. This metric does not reflect that separate parts of the distribution (quantiles) may trend differently over time. It appears that no literature statistically analyses the quantiles of PCE, but several papers motivate this work and use comparable techniques. Neal & Roche (2020) applied a quantile technique to analyse differences in factors between farms in the top quartile of return on assets and those outside this cohort using 12 years of data. They found that the top-quartile farms had significantly greater levels of PCE per hectare than those outside of the quartile. Beca (2020) compared several countries against Australian dairy regions with respect to competitiveness and profitability and reported a positive relationship between return on capital and pasture and crop harvested. He also showed that from 2003 to 2019, New Zealand generated the highest level of dry matter (DM) from pasture and crops on average, but this has stagnated over the sample period. Neal et al. (2019) applied a quantile methodology to PCE data to calculate the potential pasture DM for a farm. They considered the 90th percentile to be a proxy for the pasture potential that a farm can attain in a given location, which is mediated by several factors such as climate, elevation, soil type, crop type, and levels of irrigation and nitrogen (N) use. The pasture potential represents the 90% quantile of PCE that farms within a radius with similar geographical characteristics achieve. Chapman et al. (2020) found that between 2004 and 2019, pasture eaten plateaued nationally on farmlet trials, and at the regional level in industry statistics.

This study aimed to: 1) determine the stability of PCE over time for regions throughout New Zealand; and 2) quantify the differences between top-, average- and bottom-performing farms over time.

Materials and Methods

Data

Data were used from DairyBase, a farm performance database (DairyNZ 2020a), comprising the 2005-2006 to 2018-2019 annual production seasons. The database contains farm-level variables derived from each participating farm's financial accounts, with extra

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biophysical data obtained through a survey sent to farmers. Approximately 700 farmers per year respond to the biophysical data survey, with a significant overlap in respondents between seasons. Farm-level data from Northland, Waikato, Marlborough-Canterbury (henceforth Canterbury) and Otago-Southland (Otago) were analysed, enabling a detailed analysis of climatically-divergent regions while maintaining a reasonable sample size. Regional zones in this analysis are defined by boundaries used in the Economic Farm Survey (DairyNZ 2020b). Summary statistics and the range of sample sizes across seasons of PCE per hectare are presented in Table 1.

DairyBase gives PCE in t DM/ha based on a farm's effective dairy platform, which is the total area available for grazing or cropping, excluding the support block. The amount of pasture and crop that the herd consumes on a farm is impractical to measure. Hence, PCE estimates were back-calculated using the herd's total annual energy requirements (Nicol & Brookes 2007), converted to kilograms of DM using a standard metabolisable energy of 11 MJ ME/kg DM, less the quantity of feed from imported supplements and off-farm grazing (DairyNZ 2016). A consequence of this approach was the necessity to consider both pasture and crop consumption jointly. DairyBase records the crop area in hectares using the biophysical survey. However, approximately 46% of the values are recorded as zero, and the 90th percentile of crop area grazed by dairy cows is less than 10% of the effective dairy platform. Pasture and crop eaten values were adjusted for N fertiliser use, assuming a response rate of 10 kg DM per kg N (Neal et al. 2019). Correcting for N use avoids the PCE trend capturing a N intensification or de-intensification effect. DairyBase data were used from the biophysical questionnaire on N use per hectare. This variable has some measurement error where respondents have entered zero rather than the actual value. An imputation for N use per hectare was used when the value was zero or if the farm was missing a value in a year but had other sample data for N use. This imputation used fertiliser expenditure, stocking rate, production season fixed effects and farm level fixed effects to estimate N use. The imputation explained 94% of the variation in N use per hectare in the dataset. Furthermore, when the actual N use was zero, the model correctly predicted this in most cases.

Statistical Methodology

Pasture and crop eaten values were analysed using quantile regression after adjusting for N use. A quantile is the set of values that divide a variable into a pre-defined number of groups, each with equal numbers of observations, i.e., each group contains a similar proportion of the total sample. Unlike linear regression, which characterises all observations by the average, a quantile regression model (Koenker & Bassett 1978) relaxes this assumption by modelling the PCE distribution (P_{it}) for farm i at time t with region-specific intercepts and time trends that vary by quantile. Furthermore, the model includes an error term to allow statistical inference to be performed on the parameters. Quantiles from 10% to 90% in 10% increments were analysed, emphasising the 50% quantile (known as the median) and the 90% quantile (henceforth referred to as the frontier). Farms with less than three observations in the sample were excluded because many of them entered the sample during the 2013-2014 to 2016-17 seasons, causing an artificial change in the sample quantiles in those seasons. Their exclusion omitted approximately 25% of farms in the distribution, with each region having a similar proportion removed. A t-test was performed on the regional time trends to test the significance of the regression slope coefficient, with a significant P-value implying that the trend of PCE distribution for a region was non-zero over time. Using a t-test assumed that the model produced normally distributed errors; a visual inspection of a quantile-quantile plot indicated errors consistent with a normal distribution.

To characterise farms by their PCE performance over time, a subset of the data was taken that contained the first five observations for any farm that had a minimum of five sample points in the dataset. This approach ensured that earlier years in the sample were represented. Top performers were farms that exceeded the 75% regional percentile of PCE for 4 of the 5 years in the sample. Bottom performers were farms that were lower than the 25% regional percentile for 4 of the 5 years. Average performers were all farms that did not satisfy the conditions of the two former groups. Using five observations for all farms ensured that every farm had equal opportunity to enter the top or bottom performance groups. There were 22 top farms, 291 average farms and 21 bottom farms across the four regions in

Table 1 Summary statistics of the pasture and crop eaten per hectare (t DM/ha) before correcting for N fertiliser use per hectare.

Region	Sample Size Range	Mean	Median	Standard Deviation	Minimum	Maximum
Northland	12 – 52	9.5	9.3	2.0	4.7	17.7
Waikato	73 – 185	12.5	12.5	2.2	4.9	19.5
Canterbury	25 – 76	14.4	14.7	2.1	7.1	20.6
Otago	20 – 64	11.5	11.5	2.0	5.0	18.6

the dataset. A linear mixed model was used with fixed effects for the region-specific intercepts and time trends, and random effects for farm-level intercepts and time trends. The top-, bottom- and average-performing trend coefficients were considered at the national level. A Kruskal-Wallis test (Kruskal & Wallis 1952) was used to perform pairwise hypothesis tests to determine whether the groups came from different underlying distributions. A significant Kruskal-Wallis test statistic provided evidence that one of the groups was drawn from a different distribution. A signed-rank test (Wilcoxon 1945) was used to test if the group medians of the distribution varied significantly from zero. A boxplot was used to highlight the distributional differences between the groups, with the P-values of the Kruskal-Wallis test displayed on the graph. For these tests, a P-value less than 0.05 (P<0.05) is considered significant, P<0.01 is highly significant and P<0.001 is very highly significant.

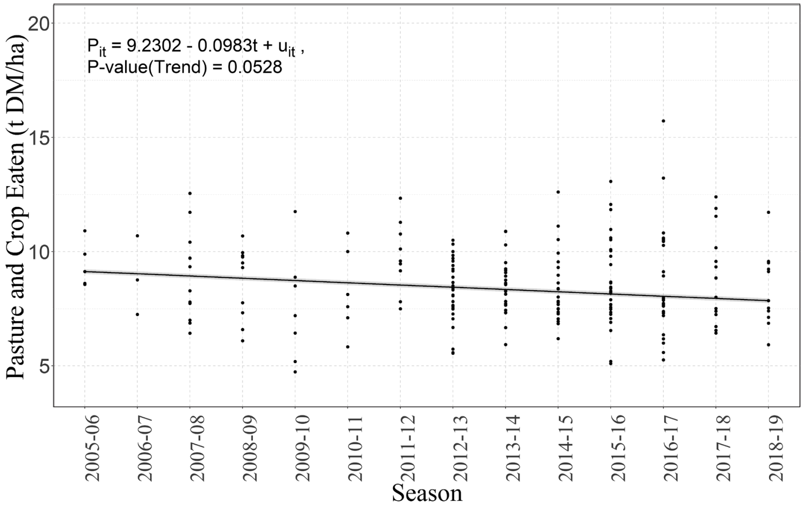

Figure 1 50% quantile regression of pasture and crop eaten per hectare (P_{it}) against season (t) in Northland from 2005-06 to 2018-19.

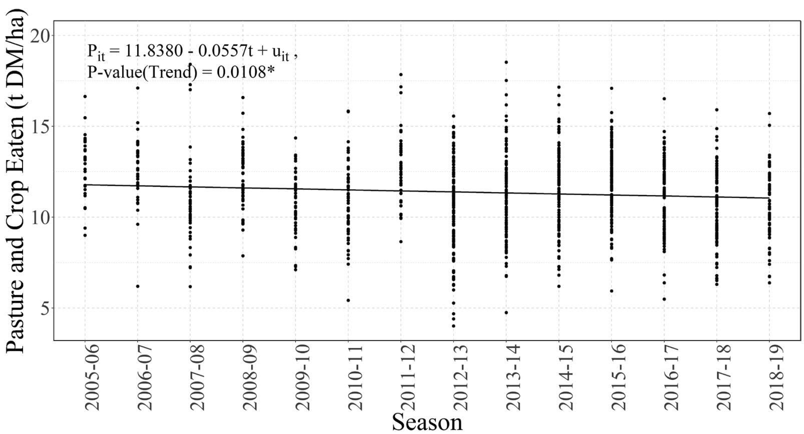

Figure 2 50% quantile regression of pasture and crop eaten per hectare (P_{it}) against season (t) in Waikato from 2005-06 to 2018-19.

The R programming language (R Core Team 2020) was used to perform the analyses; specifically, the *quantreg* package (Koenker 2020) performed the quantile regressions, and the *ggplot2* package (Wickham 2016) provided all the graphical and visual elements.

Results

Regional-scale quantile regressions

The trend of the median quantile regression line was lower than zero for Northland (P<0.10) with a coefficient of -0.098 (i.e., a reduction of 98 kgDM/ha/yr) (Figure 1). Waikato had a significant trend coefficient for the median quantile (P<0.05) with a coefficient of -0.056 (Figure 2). Both the Canterbury (Figure 3) and Otago (Figure 4) trend coefficients for the median quantile were non-significant.

For the 90% quantile regression, the regression lines contained many of the points below the trend lines. This reflects that the trend line was modelled such that 90% of the observations were below this line. The Northland (Figure 5) and Waikato (Figure 6) trends were not significantly different from zero. In contrast, Canterbury had a trend coefficient that increased at a rate of 66 kg DM/ha/yr (P<0.1, Figure 7). The trend of the line for Otago was lower than zero (P<0.01) with a coefficient of -0.106, representing an annual decline of 106 kg DM/ha/yr (Figure 8).

National-scale farm performance metric

Median trend coefficients (t DM/ha/yr) for performance groups were in the order bottom (0.149) > average (0.043) > top (-0.015) (Figure 9). The Kruskal-Wallis test found significant differences between the

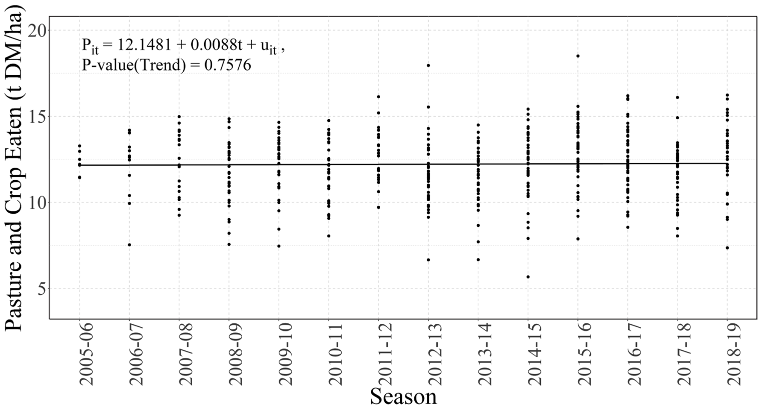

Figure 3 50% quantile regression of pasture and crop eaten per hectare (P_{it}) against season (t) in Canterbury from 2005-06 to 2018-19.

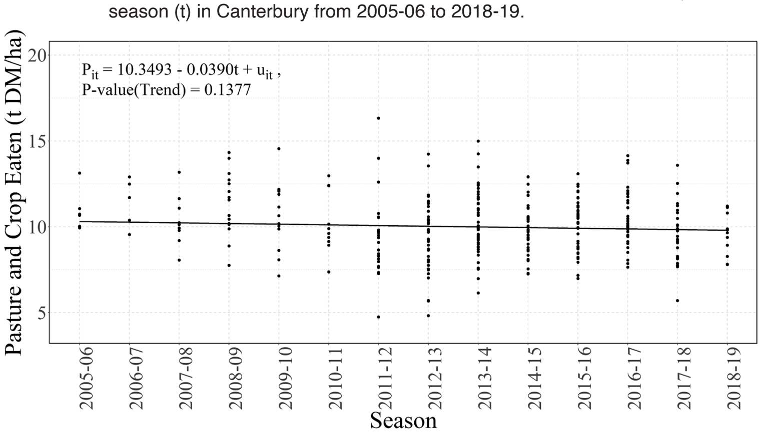

Figure 4 50% quantile regression of pasture and crop eaten per hectare (P_{it}) against season (t) in Otago from 2005-06 to 2018-19.

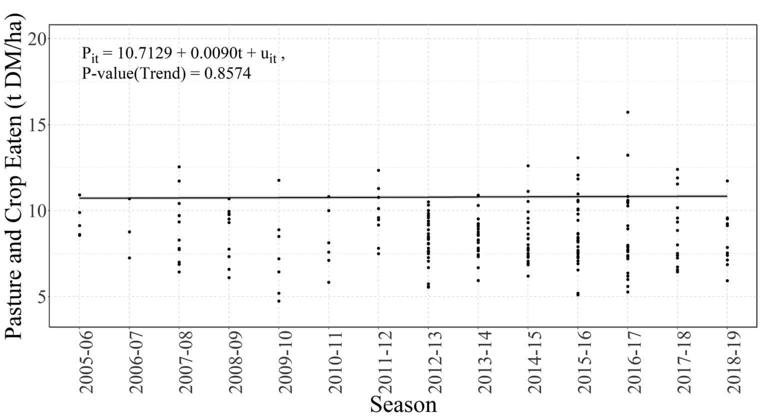

Figure 5 90% quantile regression of pasture and crop eaten per hectare (P_{it}) against season (t) in Northland from 2005-06 to 2018-19.

bottom and average groups (P=0.0110), the average and top groups (P=0.0150), and between the bottom and top groups (P=0.0024). The medians of the trend coefficients varied from zero for the bottom-performance group (P=0.0028) and the average group (P<0.0001), whereas the coefficient for the top-performance group did not differ significantly from zero (P=0.5235, Table 2).

Discussion

New Zealand's ability to rely on pasture is a key driver of operating profit for a farm and has historically given the dairy industry a competitive cost advantage in international markets (Beca 2020; Neal & Roche 2020). This study showed how recent forage intake (PCE) per hectare varied between dairy farms in geo-climatically different regions across the country, identifying similarities and differences in trends over time. It also determined temporal trends in the performance of farms with different PCE/ha levels. Collectively, this information is valuable in appraising the recent performance of pasture resources on New Zealand's dairy farms and suggesting future short-term trends.

The quantile regression results at the regional level showed a wide range of outcomes. PCE declined in the median quantile

Table 2 Descriptive statistics of trend coefficients (t DM/ha/yr) by performance group at the national scale.

Performance Group	Mean	Median	Standard deviation	Wilcoxon P-value
Bottom	0.152	0.149	0.20	0.0028
Average	0.056	0.043	0.14	<0.0001
Top	-0.019	-0.015	0.12	0.5235

for Waikato at 56 DM/ha/yr (Figure 2) and in Northland at a rate of 98 kg DM/ha/yr (Figure 1). PCE for frontier farms (90% cohort) declined at 106 kg DM/ha/yr in the Otago region (Figure 8). In contrast, there was a positive trend in the Canterbury frontier, increasing at a rate of 66 kg DM/ha/yr (Figure 7). The prevalence of irrigation is a key difference between Canterbury and the other regions. Irrigation is more accessible in Canterbury, allowing farmers to irrigate during dry periods when low soil moisture levels would otherwise limit growth (Martin et al. 2006). Half of the trends were not found to be significant (i.e., P>0.05). Overall, the results showed a general lack of an upward trend in PCE at the regional level, which is consistent with other research showing that pasture harvest levels have plateaued both nationally (Beca 2020) and regionally (Chapman et al. 2020). There are several key reasons why PCE may not be increasing for median or frontier farms. First, supplement expenditure varies across time but has increased at around 3% annually, on average, for the last decade. The use of supplement can offset pasture intake because of substitution, with substitution influenced by the type of supplement, time of year, and level of pasture ingestion (Stockdale 2000). Second, these trends may indicate climate effects, with extended summer-autumn dry periods reducing annual pasture supply due to decreased tiller density and reduced herbage accumulation (Chapman et al. 2011; Glassey 2011). Third, despite the significant expansion of the New Zealand dairy sector over the last 30 years, there is empirical evidence that stocking rates have stabilised over the last decade (LIC & DairyNZ 2020). This suggests that any gains in pasture utilisation associated with increases in stocking rate (Macdonald et al. 2008) are likely starting to plateau. Fourth, a lack of

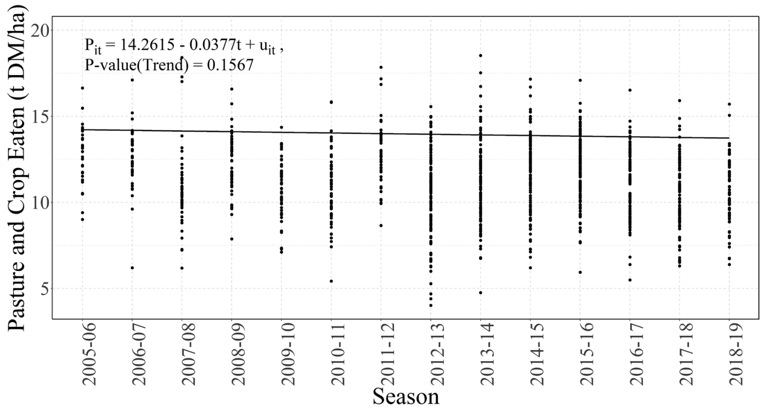

Figure 6 90% quantile regression of pasture and crop eaten per hectare (P_{it}) against season (t) in Waikato from 2005-06 to 2018-19.

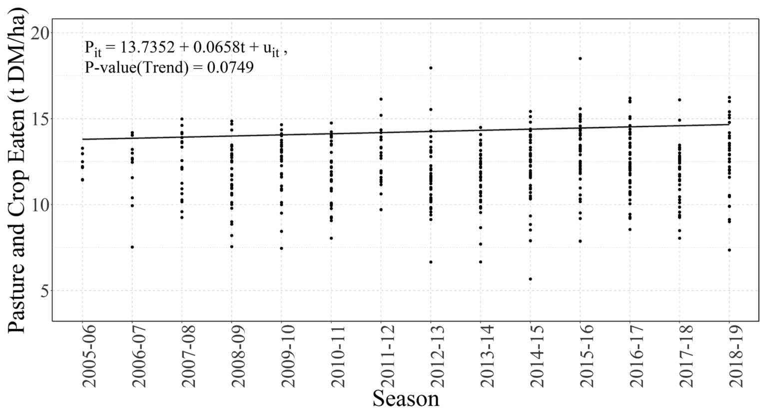

Figure 7 90% quantile regression of pasture and crop eaten per hectare (P_{it}) against season (t) in Canterbury from 2005-06 to 2018-19.

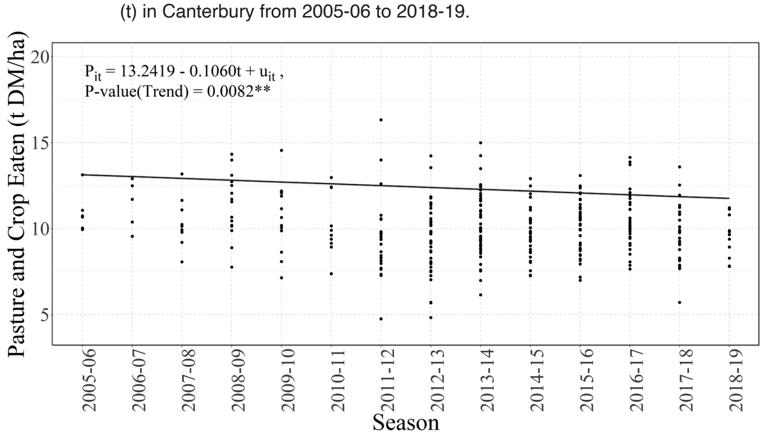

Figure 8 90% quantile regression of pasture and crop eaten per hectare (P_{it}) against season (t) in Otago from 2005-06 to 2018-19.

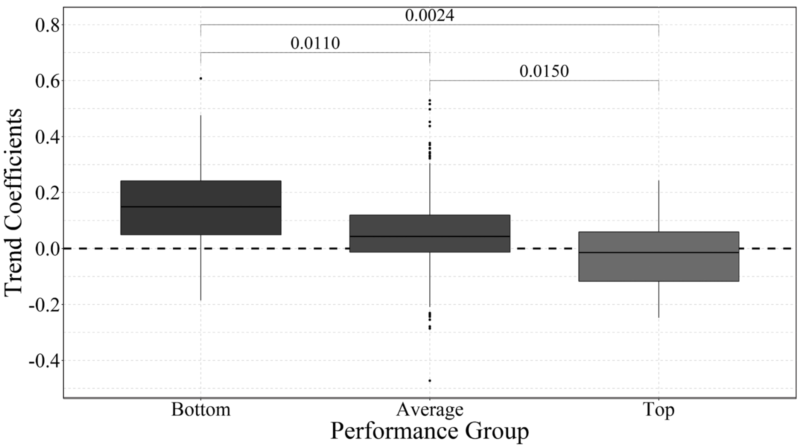

Figure 9 Boxplot of farm-level time trend coefficients (t DM/ha/yr) by performance group. P-values of differences between groups are presented at the top of the figure.

upward movement highlights the existence of potential barriers to technical innovation in pasture and crop science or the dissemination of innovations, even among efficient early adopters on frontier farms. Fifth, the rapid expansion of the New Zealand dairy sector (cows and land area) and supplement use may have grown faster than pasture management skills in the sector, to the extent that PCE may be declining, as found in this study. The relative importance of each driver is likely to vary regionally, given broad diversity and regional farm management and performance (DairyNZ 2020b). Lastly, farmers on the PCE frontier may lack improvement due to diminishing returns from existing technologies, while limited research may have inhibited the development and uptake of new technologies. Farmers below the frontier have opportunities to use existing technologies to improve PCE but face factors that restrict their adoption of these technologies, such as environmental constraints, risk aversion or a lack of management expertise. Future research should provide further understanding of the specific drivers of these negative trends across each region for frontier and non-frontier farms.

The New Zealand dairy sector is second only to the European Union in the global dairy trade, producing a third of traded milk products (Hemme 2020). The ability to source high levels of feed from home-grown pasture and crops is a key driver of the New Zealand dairy sector's competitiveness, helping it to maintain a low cost of milk production relative to more intensive sectors overseas (Neal et al. 2019; Neal & Roche 2020). The results reported here show that some quantile trends are decreasing across the regions. A downward trend at the median would be concerning because it characterises that at least 50% of the farms in the region are exhibiting decreasing PCE over time. A downward trend at the frontier would be concerning because it suggests that opportunities for future progress in the region are restricted. Waikato and Northland have trends that decrease around the median, and Otago has a trend that is decreasing in the frontier.

The current business context facing New Zealand dairy farms reinforces the importance of these findings. First, high debt loads in the sector (Dunstan et al. 2015) emphasise that efficient use of home-grown feed should be a key focus for all farmers. Second, New Zealand has made a national commitment towards reducing greenhouse-gas emissions and N loss from agriculture. While increasing pasture harvest is associated with higher profit, it can exacerbate N loss and methane production. The negative effects can be mitigated if farmers decrease supplementary feed, at least partially, to offset the increase in pasture harvest, as this dampens the cost of mitigation (Doole & Kingwell 2015). Third, New Zealand dairy pastures remain predominantly populated by perennial ryegrass. Stable or declining intake as indicated in this study suggests a potential issue with the performance of ryegrass for home-grown feed. Several mitigation options exist, such as diversifying pasture mixes (Doole et al. 2021), implementing effective N application and providing irrigation during dry periods. Last, recent research suggests that national dairy farm efficiency — the ability of a farm to produce more from less — has stabilised over the last decade (Romera et al. 2020). The low cost of home-grown feed relative to imported supplement is a key driver of farm efficiency (Neal & Roche 2020). Thus, it is likely that stable or declining trends for PCE are a key driver of this static efficiency result. This outcome reinforces the need to improve this key aspect of production.

Where small groups of individual farms are categorised as top, average or bottom performers relative to regional potential, at the national level there may be some improvement of poorer performers towards the frontier cohort, but no net progress for the top group (Figure 9). While there are no obvious medium to long term data sets to confirm this finding, the lack of progress for the frontier cohort is supported by the lack of a positive trend in DairyNZ research farm data, which achieves PCE levels similar to the top farmers (Neal & Cooper 2016; Chapman et al. 2020). An avenue of future research using this farm performance metric would be to analyse the differences between the performance groups for other covariates like milk production, stocking rate, climate and supplementary feed use. This research would begin to disentangle the underlying reasons for the top echelon's stagnation in three of the four regions. Improved pasture genetics should be expressed on-farm through improved yields. However, the stagnation at the farm level (for a dataset spanning 14 years) appears inconsistent with the continued increases in breeding trial yields (Harmer et al. 2016). A possible cause of this are circumstances that lead to theoretically improved genetics without improved outcomes on-farm, for example, climatic challenges leading to no significant improvements in milk production when using pasture mixes with improved ryegrass genetics (Woodward et al. 2001). Furthermore, pest pressures may reduce actual yields relative to theoretical yields, with severity being dependent on climatic conditions among other factors (Lane 2011). The positive trend in the Canterbury region at the frontier, suggest that further research would be useful to identify the drivers of this result. Here, broad-scale adoption of high-yield forage crops (e.g., fodder beet) and irrigation may be especially important. The prevalence of irrigation in this region, relative to the rest of New Zealand, may emphasise the importance of climate in determining trends for pasture and crop intake in other parts of the country.

Conclusion

The current literature proposes that PCE is stagnating at the national level using aggregated data and at the regional level using experimental farm data. This study extended these results to the regional level using a detailed longitudinal farm data set, finding no substantial evidence of regional improvement in PCE at the median or the frontier. Furthermore, it found that the top performers are not improving in PCE, while average and bottom performers may be marginally improving. The lack of improvement in top performers is highly concerning because it suggests a limit to the New Zealand dairy sector's PCE. The improvement in average and bottom performers is encouraging but is not sufficiently fast enough to maintain New Zealand's dominance in pastoral-based dairying. Both results are highly concerning for the dairy sector's international competitiveness, making further research into technologies and techniques that improve pasture yields paramount to the industry.

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