Cows, cash and climate: Low stocking rates, high-performing cows, emissions and profitability across New Zealand farms

David Fleming, Suzi Kerr and Edmund Lou

Motu Working Paper 19-11

Motu Economic and Public Policy Research

May 2019

Document information

Author contact details

David A. Fleming-Muñoz

Affiliation during work: Fellow, Motu Economic and Public Policy Research

Current affiliation: Senior economist, CSIRO

david.fleming@csiro.au

Suzi Kerr

Affiliation during work: Senior Fellow, Motu Economic and Public Policy Research

Current affiliation: Chief Economist, Environmental Defense Fund

skerr@edf.org

Edmund Lou

Affiliation during work: Research Analyst, Motu Economic and Public Policy Research

Current affiliation: Doctoral Student, Northwestern University

edmund.lou@motu.org.nz

Acknowledgements

This work was conducted as part of the project "Barriers to Adoption of 'No-cost' Mitigation Options" funded by the New Zealand Government to support the objectives of the Livestock Research Group of the Global Research Alliance on Agricultural Greenhouse Gases. We are grateful for advice and input from Robyn Dynes and Cecile de Klein at AgResearch. Thanks to Bronwyn Bruce-Brand for help with some final analysis.

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Motu Economic and Public Policy Research

PO Box 24390 | info@motu.org.nz | +64 4 9394250
Wellington | www.motu.org.nz
New Zealand

Abstract

Using the New Zealand Monitor Farm Data (NZMFD), this paper explores the cost-effectiveness of two mitigation options to reduce biological greenhouse gas (GHG) emissions on farms: reducing stocking rate (SR; the number of cows per effective hectare of dairy land); and increasing animal performance (AP; measured by production of milk solids (MS) per cow). These mitigation options have been defined as "no cost" because, if applied together, they could reduce the carbon footprint of farms while also maintaining or even improving profits (de Klein & Dynes, 2017).

We evaluate the effect of these mitigation options on three main variables: milk profitability of the farm (cash operating surplus (COS)/ton of MS produced); emissions intensity (ton CO_2eq/ton of MS produced); and the value of emissions (COS/ton CO_2eq). The paper has two main findings: high-AP farms show significantly lower emissions intensities and higher milk profitability; and higher SRs on farms are significantly associated with lower emissions intensities while not being significantly associated with milk profitability or negatively associated with profit per hectare. These results imply that higher levels of AP reduce the GHG intensity of the farm and increase profit – a "no-cost" option – but unless either the SR or the area under dairy farming fall, an increase in AP will lead to an increase in absolute emissions. However, our results cast doubt on the idea that reducing SR is a no-cost way to achieve absolute emission reductions. The two options do seem to constitute a no-cost outcome when combined, but potentially the same mitigation could be achieved with lower loss of profit by reducing the area of dairy land while maintaining high SRs and increasing the performance of the animals.

JEL codes

Q10, Q19, Q52, Q54

Keywords

value of emissions, agricultural greenhouse gas emissions, climate change, dairy, methane, nitrous oxide, emissions intensity, mitigation practices, pastoral systems

Summary haiku

Better cows are good
Doubt about low stocking rates
Farms are complex things

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1 Introduction

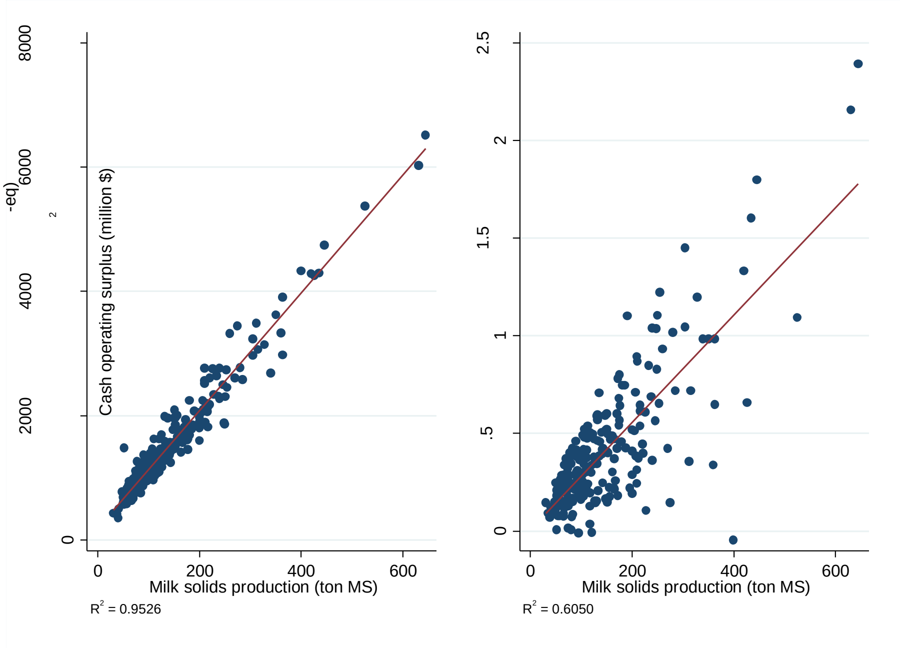
For New Zealand to transition to a low-emissions economy, farmers need to reduce the biological greenhouse gas (GHG) emissions produced by their operations.[1] Ideally, this would be done in an efficient way. Two definitions of "efficient" could apply. First, we might want farmers to have the highest profit per unit of GHG they do emit to maximise the value of those emissions to New Zealanders, and conversely reduce absolute GHG emissions most when they bring least value. Second, if biological emissions are priced and there is strong concern about international leakage, we might want farmers to achieve high levels of production from each unit of GHG emitted. In this paper, we explore the potential for achieving these two complementary goals in dairy farming. We do this by looking at two farm practices that could reduce emissions intensity while maintaining or even improving profitability: a low stocking rate (SR) combined with high animal performance (AP).

From a commercial and landowner's point of view, it would be ideal if there were no conflicts between profitability, production and GHG emissions. But is this too optimistic? Higher profits are often perceived to be associated with higher production, and higher production with higher levels of GHG emissions. Figure 1 indicates such relationships for dairy farms reported in the New Zealand Monitor Farm Data (NZMFD) from 2009 to 2012 (Henry et al. 2017). Both GHG emissions (left-hand graph) and cash operating surplus (COS; right-hand graph) are highly positively correlated with milk solids (MS) production. However, it can also be observed that, for a similar level of MS production, farms show a range of different profit levels and GHG emissions. This indicates that management skills and practices, along with other factors such as the geophysical conditions on farms, can influence GHG emissions and profitability.

Anastasiadis and Kerr (2013) explored the relationship between GHG emissions and production using a simpler version of the same dataset. Other empirical literature employing cross-sectional farm-level data in New Zealand is scarce but includes Jiang and Sharp (2014, 2015) and Soliman and Djanibekov (2018), who also use the NZMFD dataset. This paper expands on this research, using richer data and having a stronger focus on economic outcomes of direct concern to policy.

1 In this paper we focus on biological emissions of methane (CH_4) and nitrous oxide (N_2O), and ignore agricultural carbon dioxide (CO_2) emissions from fuel and electricity use as well as carbon sequestration in forests. These CO_2 emissions and the carbon sequestration in forests are covered by the New Zealand Emissions Trading System.

Figure 1: Greenhouse gas emissions, cash operating surplus and milk solid production



The agricultural sector is the largest source of GHG emissions in New Zealand. According to *New Zealand's Greenhouse Gas Inventory 1990–2016*, biological emissions from the sector contributed approximately 49.2% of New Zealand's gross carbon dioxide equivalent (CO_2eq) GHG emissions in 2016 (Ministry for the Environment 2018). More than two-thirds of this was attributed to methane (CH_4) emissions, mainly from enteric fermentation of ruminants, and the rest to nitrous oxide (N_2O), mainly from animal urination and dung, fertiliser and soil management. Since 1990, gross emissions from the agricultural sector have risen by 12%. This increase has mostly resulted from a near doubling of the dairy herd, partially offset by reductions in sheep and non-dairy cattle and significant improvements in emissions intensity across pastoral agriculture. Considering the current importance of the dairy sector for rural communities and for the national economy, it is economically critical to find ways to reduce these emissions in a way that does not lead to significant adverse effects on the economy as a whole or on landowners and rural communities, and does not create globally perverse effects. Finding constructive solutions in New Zealand could open up much greater mitigation options in other regions of the world that have large dairy sectors.

Using the NZMFD, this paper explores the factors that distinguish dairy farms that have simultaneously high profitability and low emissions intensity from the rest. In particular, it focuses on two changes in practice that local agricultural scientists such as de Klein & Dynes (2017) have suggested could reduce emissions intensities of farms while maintaining or even improving their profitability: a low SR combined with high AP. The main research question explored by the paper is whether a low SR combined with high AP (in terms of MS production) can be considered a win–win or no-cost mitigation option – in other words, a farm practice that maintains (or improves) profits while reducing the GHG emissions of the farm.

1.1 Low stocking rate and high-performing animals as a mitigation option

A lower SR means fewer cows per hectare of effective land (land used for production). Targeting better-performing animals means improving the genetic pool of the herd by, for example, selecting animals that have a higher "breeding worth" (BW) (Macdonald et al. 2008).[2] BW ranks bulls and cows according to their expected ability to breed profitable and efficient replacements. It combines characteristics such as milk volume, milk fat, protein, fertility and longevity.

As a result of genetic improvements, research and better practices, MS production per cow has increased in New Zealand over the last 28 years. However, it has been established that it could increase even more, especially with the use of supplementary feeds (Reisinger & Clark 2016). Based on estimates from the Ministry for Primary Industries (MPI) and modelling performed by the New Zealand Agricultural Greenhouse Gas Centre (NZAGRC), Reisinger et al. (2018) state that there is "very high confidence that increasing individual animal performance is available as a potential mitigation option". However, they emphasise that it is valid only if the enhanced AP is compensated by a reduction in animal numbers, such that total product output is maintained or reduced. Increasing AP is therefore not a mitigation option per se, but rather must be combined with a lower SR.

New Zealand dairy farms operate on a spectrum from low-input systems, mostly based on pasture grasses with fewer cows per hectare, to intensive systems, with more cows and where typically up to about 40% of the total feed is imported to the farm year-round. Shifting an existing intensive farm towards lower intensity with lower SRs requires significant management skill if farm profits are to be sustained (Reisinger et al. 2018). In addition, shifting the dairy sector towards low-input systems could reduce the ability of farmers (and the industry) to take advantage of periods when milk payouts are high.

Reducing SRs generally means production and therefore farm revenue are reduced. However, a low SR could also lead to lower costs due to reduced animal demands for feed, reduced labour time, and reduced repair and maintenance costs (de Klein & Dynes 2017; Reisinger et al. 2018). The overall financial effects of lowering SRs would be driven by milk payouts and existing investments.[3] Environmentally, as a farm reduces its SR, the associated lower levels of production would lead to a decrease in the total amount of GHGs emitted, reflecting the observations in Figure 1.

[2] For more references to the BW worth trait, see https://www.dairynz.co.nz/media/532701/BW_explained.pdf
[3] Farms with better infrastructure, requiring less labour time to manage a reduced SR system, for instance, might be better positioned to profit than farms that have not made infrastructure improvements.

Several New Zealand studies have found that, by combining low SRs and high AP(for example, through the introduction of high-BW animals), a reduction in GHG emissions is possible while also maintaining or even improving farm profits (see de Klein & Dynes 2017 for a collation of evidence). However, the evidence for this has come from farm models or from data collected in research trial farms. In other words, to the best of our knowledge the suggested combined effects of these practices on both GHG and profits have not been validated with a cross-sectional sample of farms from different regions of the country. We address this evidence gap by using the NZMFD.

The remainder of the paper is structured as follows. Section 2 describes the NZMFD and provides summary statistics for the variables we use. Section 3 presents what we call a “four-quadrant analysis”, which defines “efficient” farms based on two characteristics: their level of *emissions intensity* (total on-farm biological GHG emissions divided by total MS produced); and their level of *milk profitability* (the farm’s COS divided by total MS produced). This section also employs different econometric models to explore the drivers of variation in emissions intensity and in milk profitability between and within farms over time, paying special attention to SRs and AP. These relationships are of direct relevance to the question of low-cost mitigation while avoiding emissions leakage. Section 4 analyses what we define as the “value of emissions” (or the level of farm profits in relation to the amount of GHG emitted by the farm) and its relationship with farm SRs and AP. Section 5 describes some research caveats, and section 6 concludes the paper.

2 The New Zealand Monitor Farm Data (NZMFD)

In this paper we use the NZMFD, a dataset that contains information about the financial and production characteristics of each individual farm as well as their environmental impacts. Financial and production variables were collected by the Ministry of Agriculture and Forestry under the Farm Monitoring Programme, a project designed to provide annual summaries of different farm types across New Zealand (e.g. Ministry of Agriculture and Forestry 2010), while environmental variables were derived from Overseer 6.2.1, an agricultural decision support tool developed by AgResearch.[4] The NZMFD is an unbalanced panel covering four years, from 2009 to 2012. It contains data from 223 dairy farms, 165 sheep and beef farms, and 19 deer farms.[5] We analyse only the data related to dairy farms for two reasons: first, there is no standard output measure from sheep and beef farms; and second, the sample size of deer farms is small. Summary statistics of key variables used in this paper are reported in Table 1.

[4] For more details on Overseer, see https://www.overseer.org.nz/overseer-explained. MPI contracted AgFirst to create Overseer files for each of the monitor farms during this time period. AgResearch ran these files through the more recent version of Overseer to provide the data we use in this paper.
[5] For more information on the NZMFD data, see Henry et al. (2017). For an application, see Soliman and Djanibekov (2018).

Table 1: Summary statistics of key variables (*n* = 222)

	Mean	Std. dev.	Min.	Max.
GHG emissions (tons CO_2eq)	1,596.77	968.70	349.16	6,513.70
Cash operating surplus (million $)	417,449.6	346,066.9	-45,776	2,391,055
Cash operating surplus (thousand $) per ton of milk solids	2871.30	1244.61	-114.44	5795.13
Cash operating surplus (thousand $) per hectare	2768.29	1480.59	-107.71	8385.89
Farm profit before tax (million $)	0.16	0.27	-0.950	1.70
Total effective area (hectares)	154.78	86.70	40	481
Number of cows in milk	415.20	238.45	113	1595
Stocking rate (cows/hectare)	2.78	0.61	0.86	4.10
Milk solids production (tons)	149.32	99.3	31	645
Milk solids (tons) per cow	0.35	0.06	0.23	0.55
Milk solids (tons) per hectare	0.97	0.30	0.23	1.76
Value of emissions ($/ton of CO_2eq)	262.45	118.43	-10.59	550.47
Milk profitability ($/ton of MS)	2,871.30	1,244.61	-114.44	5,795.13
Emissions intensity (tons CO_2eq/$)	11.1450	1.6721	7.4606	16.4578
Hay and silage feed expenses per cow ($)	176.93	110.84	5.364	561.108
Animal health expenditure per cow ($)	75.425	26.315	21.441	173.647
Depreciation per cow ($)	591.667	313.365	-177.337	1706.517

Notes: Only two observations reported a negative value for depreciation.

We measure farm profits using COS, which is the net farm income less farm working expenses (Ministry of Agriculture and Forestry 2010). COS is a financial measure that does not include rent payments, stock value adjustment and depreciation. In this way, we measure farm operational performance in a particular year, removing the costs related to past or long-term financial liabilities (such as debt and rent contracts) or/and adjustments made with depreciation or stock revaluation. All calculations were also conducted using farm profit before tax (FPBT; the closest variable in our dataset to the widely used earnings before interest and taxes, or EBIT) instead of COS, where we obtained structurally similar results – these are provided in Appendix A.

The NZMFD is not ideal for exploring emissions and productivity questions. We use it because it is the only publicly available dataset that includes farm-level data on practices, emissions and profitability (nor are there any private datasets of equivalent or better quality).

There are three key issues with the NZMFD. First, the farm-level data are not necessarily representative of current New Zealand pastoral systems. The NZFMD dataset is constructed from observations made in 2009–12, so from farms that are likely to have changed during the last six years. However, the figures in our NZMFD data are not drastically different from the national average reported by dairy statistics or from a sample DairyNZ recently created to monitor GHG emissions and management (although these also come from a non-random sample). For instance, the average SR in dairy statistics is 2.85 and the average from the DairyNZ sample is 2.94 (Davidson & Newman 2017).[6] In comparison, the SR in the NZMFD data is 2.78 cows per effective hectare of farmland.

Nor is NZMFD sample random. Although MPI chose which farms to approach, those that participated in the New Zealand Farm Monitoring Programme did so on a voluntary basis; the sample probably therefore suffers from some amount of self-selection bias. The other potential data source, DairyNZ's DairyBase, suffers from the same limitation.

Second, our emissions estimates are generated from Overseer 6.2.1 and based on data from earlier Overseer files. AgResearch generated the emissions data used in our sample from old Overseer files by running them through Overseer 6.2.1. However, this is not the latest version of Overseer and, probably more importantly, some data needed to run even this version were not available in the old files, so default values were used.

Third, each farm represents a complex system in which several management decisions (including SR and investments in higher-quality cows) are made simultaneously. There is no source of random variation in our variables of interest. This means that our analysis cannot identify causal relationships. What we can explore is associations among variables within a system. In addition, many potentially relevant farm practices are not recorded in the dataset.

3 Mitigation options and efficient farms

Figure 1 shows that farms producing similar amounts of MS can have different levels of GHG emissions and profits. Some combination of the different geophysical characteristics of the farms and different management practices implemented by the farmers account for these differences. It is natural to ask, in farms with similar geophysical characteristics, what farmers who make more profits (or milk) and produce less GHG emissions do that is different. We then consider the following linear regression equation:

$$y_{it} = \alpha + \xi_{it} + \beta X_{it} + \eta_{it} \qquad (1)$$

Here, y_{it} corresponds to either emissions intensity or milk profitability of farm i in year t, X_{it} is a vector of geophysical and regional variables, ξ is year fixed effects, and η is the error terms, with mean 0. Therefore, the residual, $\hat{\eta}_{it}$, is associated with emissions intensity or milk profitability after controlling for observable geophysical variation and region.[7] The "region" variables will reflect a mixture of local geophysical characteristics not otherwise captured, and

[6] The data from the sample of farms that DairyNZ has created to monitor GHG emissions and management practices are not publicly available.

7 For emissions intensity, this approach can be viewed as a linear approximation of the relationships between geophysical characteristics and GHG emissions in the Overseer model (Wheeler et al. 2008), but it also reflects their relationship with production and, for milk profitability, costs. The geophysical characteristics include: topography (dummy variables for easy hill, rolling hill and steep hill), soil type (dummy variables for peat, podzol, pumice, recent YGE, sands and volcanic), region of the farm (dummy variables for Canterbury, Northland, Southland, Taranaki, and Waikato and Bay of Plenty), rainfall and temperature.

also systematic differences in farm practices between farms that have recently converted to dairy, such as many in Canterbury or Southland, relative to those in long-established dairy regions such as Waikato or Northland.

In Figure 2 we illustrate how the residuals of emissions intensity are associated with those of milk profitability. The residuals estimate the effects of farmers' unobserved management decisions. The horizontal line is the median of emissions intensity residuals; the vertical line is the median of the residuals of milk profitability. We define the farms in the fourth (bottom right) quadrant as "efficient" farms. By this definition, efficient farms have high profitability and low emissions intensity as a result of unobservable characteristics, including farmers' management decisions. As can be seen, there is no clear association between milk profitability and emissions intensity residuals.[8] It is not obviously costly (or profitable) for farmers to reduce emissions. This is supported further by Figure 3, which shows the residuals relationship of sub-samples of farms by region.[9]

Figure 2: Emissions intensity residuals and milk profitability ($ per ton of milk solids) residuals

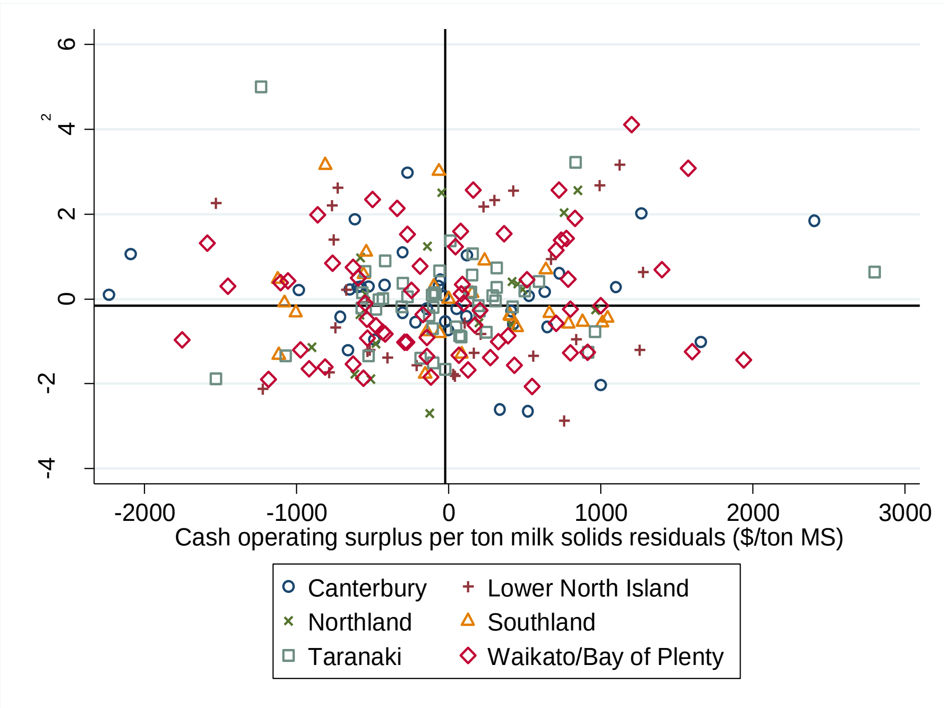
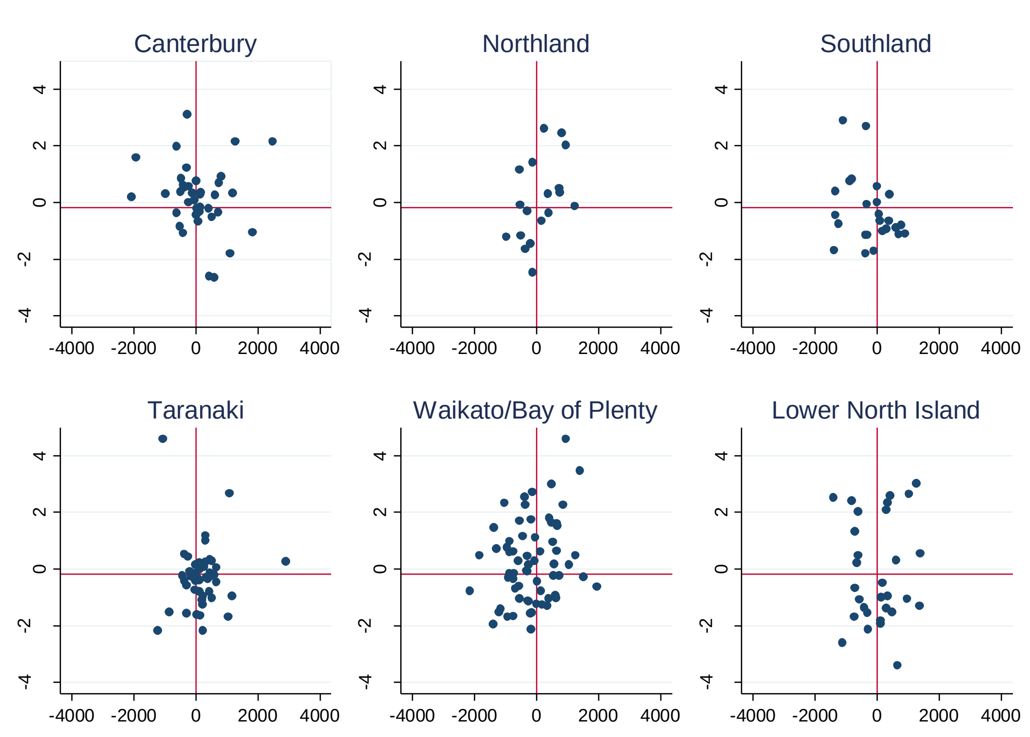


Figure 3: Emissions intensity residuals and milk profitability ($ per ton of milk solids) residuals per region

8 This was also true before controlling for geophysical characteristics and region.
9 As we are using sub-samples of the data by region, the residuals plotted in Figure 3 do not include the "region" variables in their estimation.



We now explore farm characteristics and, in particular, management practices that could explain some of this variation. Table 2 summarises statistics of key practices and farm characteristics variables divided into two sub-samples: efficient farms (those located in the bottom right quadrant of Figure 2) versus non-efficient farms (all other quadrants). On average, efficient farms have higher MS per cow in milk (what we define as AP) and higher MS per hectare of effective area than non-efficient farms. Counterintuitively, our descriptive statistics show that efficient farms are likely to have higher SRs. This is consistent with efficient farms producing more milk per hectare. Farms with higher animal numbers and a higher intake of dry matter may be more likely to be efficient but total size in hectares is unrelated to efficiency. Efficient farms also have a lower nitrogen leaching rate (and a lower but less clearly significant leaching rate for phosphorus). This suggests that practices that lower nitrogen leaching also reduce GHGs. This is consistent with work carried out by Shepherd et al. (2016). Farms that spent less on (any kind of) fertiliser per kilogram of MS are also more likely to be efficient.

Table 2: Efficient and non-efficient farms by averages of continuous management practices[10]

	Farms		t-test	Wilcoxon rank-sum test
	Efficient (n = 57)	Non-efficient (n = 165)		
Milk solids (tons) per cow (animal performance)	0.37 (0.01)	0.34 (0.00)	-2.693***	-2.753***
Stocking rate (number of cows/hectare)	2.99 (0.08)	2.70 (0.05)	-3.081***	-2.785***
Milk solids (kg) per hectare	1,119.15 (35.96)	955.58 (21.71)	-3.894***	-3.705***
Herd size (number of cows in milk)	460.49 (35.08)	399.56 (17.70)	-1.551	-2.262**
Animal pasture intake (tons of dry matter)	1,604.17 (195.57)	1,419.16 (100.52)	-0.841	-0.934
Total effective area (ha)	156.39 (10.33)	154.22 (6.99)	-0.173	-1.100
Fertiliser expenses per kilogram of milk solids[A]	0.486 (0.024)	0.567 (0.019)	2.6317**	2.271**
Number of feed supplements imported	3.561	3.036	-2.3914**	-2.407**
Hay and silage feed expenses per cow	173.674	178.056	0.260	0.154
Animal health expenditure per cow	75.0356	75.559	0.131	0.045
Depreciation, per cow	628.256 (43.95)	579.025 (23.88)	-0.984	-0.841
Nitrogen leaching (kg N/ha)	42.77 (2.39)	51.69 (1.97)	2.875***	2.296**
Phosphorus run-off (kg P/ha)	1.74 (0.33)	2.00 (0.15)	0.713	1.696*
Characteristics that define "efficient"				
Milk profitability (cash operating surplus (S)/ton of milk solids)	3470.827	2664.196	-4.706***	-4.111***
Emissions intensity (GHG/ton of milk solids)	10.021	11.533	7.629***	6.283***
Other financial indicators				
Cash operating surplus per hectare	3,730.742 (238.2522)	2,496.265 (132.9048)	-4.5250***	-4.602***
Farm profit before tax per hectare	1,609.891 (256.775)	705.971 (129.6993)	-3.1422***	-3.069***
Value of emissions (cash operating surplus (\$)/ton of CO_2eq)	350.05 (14.81)	232.19 (8.18)	-6.965***	-6.118***

Notes: [A] Available for only 69 farms. Standard deviations are in parentheses. Asterisks denote statistical significance of test at: * p<0.1, ** p<0.05, *** p<0.01. The t-tests conducted here are those of two samples with unequal variances.

[10] Comparison statistics for additional variables are given in Appendix B.

Table 3 also shows summary statistics for the farms we define as efficient and non-efficient, but does so for three discrete management practices that we use below in our analysis.[11] It documents that a larger percentage of efficient farms used dicyandiamide (DCD).[12]

Table 3: Efficient and non-efficient farms by discrete management practice

	Farms	
	Efficient (n = 57)	Non-efficient (n = 165)
Use DCD	7	7
Use irrigation	11	31
Use feed pad	9	24

We now explore these relationships in a different way. Since some unobservable geophysical characteristics and management practices that affect both emissions intensity and milk profitability might exist, it is reasonable to assume that the error terms in the two versions of equation (1), for emissions intensity and for milk profitability, are correlated. To reflect this, we employ seemingly unrelated regression (SUR) models and estimate the following:

$$y_{ijt} = \alpha_i + \xi_{it} + \beta_{sr} sr_{jt} + \beta_{ap} ap_{jt} + \beta_X X_{ijt} + \delta Z_{ijt} + \eta_{ijt} \tag{2}$$

Here, $i \in \{1, 2\}$ indexes the equation number, j is the individual farm, and t is the year of monitoring. The dependent variable y corresponds to emissions intensity when $i = 1$ and to milk profitability when $i = 2$. The abbreviation sr stands for stocking rate and ap for animal performance, X_{it} is a vector of geophysical characteristics, Z a vector of dummy variables of management practices, ξ is year fixed effects, and η is the error terms, with mean 0. Taking advantage of the panel nature of our data (albeit unbalanced), in addition to a pooled model including all observations in our datasets, we also run regressions to explore within (farm fixed effects) and between (group means) effects. Coefficients on management variables should be interpreted as associated with a change in that variable across different farms for the "between" regressions and on the same farm across years for the fixed-effects "within" regression.

Table 4 presents the regression results. Looking first at regressors other than those of direct interest, higher expenditures per cow on hay and silage feed and on animal health are statistically associated (statistical significance at the 5% level, or lower) with lower levels of milk profitability, when comparing between and within farms. These results are consistent with

[11] Discrete because their use is reported in the NZMFD as binary variables (yes = 1, no = 0).
[12] DCD, a compound used to reduce nitrogen leaching, is a mitigation options that was available in 2012-2013 but that at the time of writing (early 2019) is not available to farmers because of an industry ban on its use as a result of residuals found in exported milk.

an argument that animals in poorer condition will require more attention from vets, increasing the cost to the farmers. Increased health expenditures on the same farm across years are positively associated with emissions intensity. In years when a farm's animals require more attention from vets, they may also be likely to emit more GHGs for each kilogram of MS produced. Depreciation per cow is positively associated with milk profitability across all three models, which is an expected result in our analysis: the higher the capital stock value of a farm (and hence its reported depreciation), the more likely it will report higher profits, as long as it has made wise investments. Depreciation per cow is, however, inconsistently related to emissions intensity. Farms with higher depreciation seem to have higher emissions intensities, while farms that increase their depreciation across years seem to lower their emissions intensity. The results relating to milk profitability are very similar when COS per hectare is used as a measurement instead of milk profitability (see Appendix C).

With respect to the coefficients on SR, in the "emissions intensity" regressions this is negative and statistically significant in the pooled and between-farms models. This means that, after controlling for all other farm characteristics, a higher SR is significantly associated with a lower emissions intensity on a farm. On the other hand, SR does not have a significant association with milk profitability, suggesting that changes in SR on farms or differences between farms do not necessarily affect milk production profit. Unfortunately, SR is significantly positively associated with profit per hectare both between and within farms (COS per hectare – see Appendix C). These results do not support the hypothesis that reducing SR is a no-cost mitigation option. Instead, they suggest that on farms in years when conditions are good for milk production (in ways not captured by the observed geophysical variables), farmers have higher SRs and also have lower costs, and hence they have higher milk profitability.

The coefficient on MS per cow (AP) is negative and significant in all three emissions intensity models, and positive and significant in the milk profitability pooled and between-farms model. These coefficients support the "no-cost" status of this option, as they show that higher AP is likely to be associated with farms that have lower emissions intensities and higher profits. This is evidence that increasing MS production per cow is a GHG mitigation option that can potentially also increase a farm's profits.

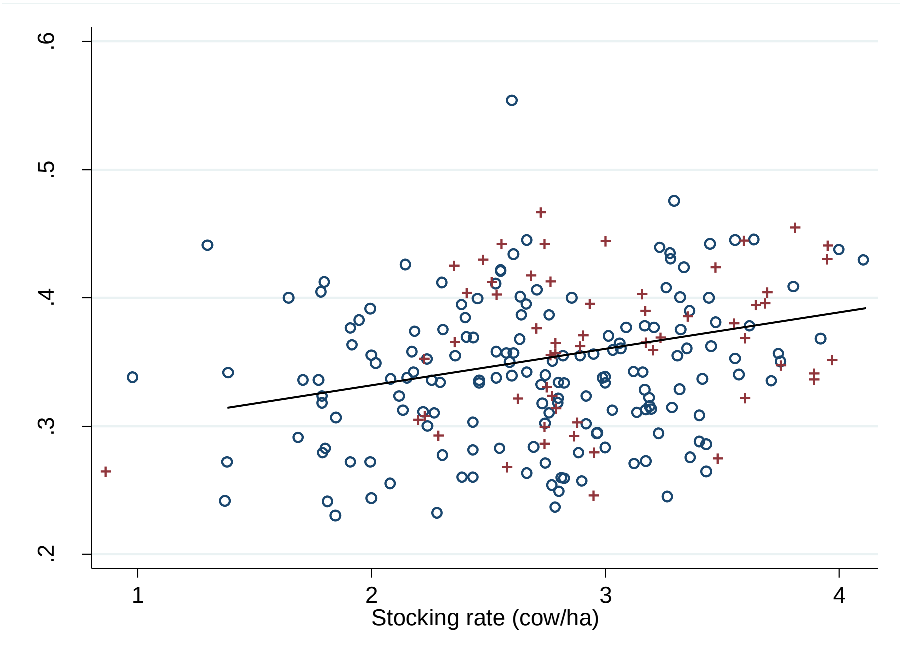
Table 4: Emissions intensity (ton of greenhouse gas per ton of milk solids), milk profitability (cash operating surplus per ton of milk solids) and mitigation options (stocking rate and milk solids per cow (AP))

	Pooled model		Between model		Within model	
	Emissions intensity	Milk profitability	Emissions intensity	Milk profitability	Emissions intensity	Milk profitability
Stocking rate	-1.110***	-111.981	-1.233***	-51.168	-0.219	231.051
	(0.157)	(103.715)	(0.184)	(118.784)	(0.222)	(201.032)
Milk solids per cow (AP)	-13.475***	2,308.734**	-11.061***	3,184.104**	-22.480***	-875.768
	(1.692)	(1,121.194)	(2.096)	(1,353.068)	(1.521)	(1,370.983)
Use of irrigation	0.184	227.275	0.154	-217.136	2.098***	-298.092
	(0.545)	(361.002)	(0.658)	(424.239)	(0.614)	(562.751)
Use of feed pad	0.079	-61.451	-0.040	-80.982	-0.645**	-334.184
	(0.221)	(145.612)	(0.252)	(162.343)	(0.268)	(245.227)
Use of DCD	-0.674**		-0.641*		-0.707***	
	(0.297)		(0.356)		(0.255)	
Hay and silage feed expenses, per cow	-0.001	-3.118***	-0.001	-3.024***	0.000	-2.350***
	(0.001)	(0.497)	(0.001)	(0.614)	(0.001)	(0.634)
Animal health expenditure, per cow	-0.001	-6.206***	-0.003	-5.395**	0.014***	-6.949**
	(0.003)	(1.957)	(0.004)	(2.219)	(0.004)	(3.402)
Depreciation, per cow	0.001***	0.514***	0.001***	0.389**	-0.001***	0.771***
	(0.000)	(0.153)	(0.000)	(0.173)	(0.000)	(0.224)
Number of supplements imported	-0.053	107.276***	-0.049	108.408**	-0.023	20.328
	(0.058)	(38.459)	(0.074)	(47.851)	(0.053)	(48.854)
Log of total effective area	-0.063	-383.566***	-0.260	-354.243**	0.274	1,125.411**
	(0.216)	(142.856)	(0.253)	(162.584)	(0.600)	(549.957)
Constant	14.677***	4,003.194***	14.535***	3,421.699**	18.499***	1,657.189
	(2.031)	(1,345.961)	(2.485)	(1,597.199)	(4.381)	(4,015.240)
Number of observations	222	222	144	144	135	135
R-squared	0.660	0.731	0.679	0.720	0.955	0.932

Notes: Standard errors are in parentheses. Regressions are conducted with additional controls, including rainfall, temperature, topography (dummy variables for easy hill, rolling hill and steep hill), soil type (dummy variables for peat, podzol, pumice, recent YGE, sands and volcanic) and regional dummies (for pooled and between-farms models). Asterisks denote statistical significance at: * p<0.1, ** p<0.05, *** p<0.01.

Figure 4 plots SR levels against AP. It can be seen that these factors are positively correlated, with a significant ρ = 0.24.[13] Could this mean that farmers with better access to capital, and possibly higher levels of skill, are able to invest in higher-performing animals (and manage them to achieve high MS per cow) and are also able to invest in, and manage, larger herds relative to other poorly resourced farmers? These farmers may also have better-quality land in ways we are unable to observe. Farms with the very lowest SRs are all (with one exception) non-efficient; similarly, the farms with the lowest AP are nearly all non-efficient.

Figure 4: Animal performance versus stocking rate



Note: Blue circles indicate non-efficient farms and red crosses efficient farms, as defined in Tables 2 and 3.

Farmers and owners of farmland are mostly concerned with profit per hectare because it relates to the value of the land and return on investments in, or lease payments for, land. In contrast, "milk profitability" relates more to the competitiveness of milk production. These factors are highly correlated but are not the same (see Appendix C).

[13] The correlation between AP and SR is higher among efficient farms (ρ = 0.28) than among non-efficient farms (ρ = 0.20).

Table 5 shows that, as with milk profitability, AP is strongly positively associated with higher profitability per hectare (even controlling for geophysical and regional characteristics). Importantly, we now see a strongly significant positive correlation between SR and profit per hectare. This suggests that reducing SR may have little effect on the profit per kilogram of MS, but seems likely to be associated with significantly lower profits per hectare.

Table 5: Seemingly unrelated regression results for cash operating surplus (COS) per hectare[14]

	Pooled model	Between model	Within model
	COS per hectare	COS per hectare	COS per hectare
Stocking rate	972.728***	1,010.735***	1,812.547***
	(111.560)	(124.691)	(236.326)
Milk solids per cow (AP)	10,779.174***	11,543.609***	9,189.524***
	(1,206.003)	(1,420.356)	(1,611.679)
Use of irrigation	-48.090	-434.921	-677.992
	(388.309)	(445.336)	(661.550)
Use of feed pad	-85.828	-141.440	-211.194
	(156.627)	(170.417)	(288.280)
Use of DCD			
Hay and silage feed expenses per cow	-3.059***	-2.824***	-2.836***
	(0.534)	(0.645)	(0.745)
Animal health expenditure per cow	-6.220***	-5.974**	-11.725***
	(2.105)	(2.329)	(3.999)
Depreciation per cow	0.502***	0.310*	1.281***
	(0.165)	(0.182)	(0.264)
Number of supplements imported	89.540**	84.118*	37.616
	(41.368)	(50.230)	(57.431)
Log of total effective area	-383.092**	-347.383**	2,267.706***
	(153.662)	(170.670)	(646.510)
Constant	-1,009.959	-1,543.470	-16,625.339***
	(1,447.771)	(1,676.627)	(4,720.174)
Number of observations	222	144	135
R-squared	0.780	0.777	0.934

Notes: Standard errors are in parentheses. Regressions are conducted with additional controls, including rainfall, temperature, topography (dummy variables for easy hill, rolling hill and steep hill), soil type (dummy variables for peat, podzol, pumice, recent YGE, sands and volcanic) and regional dummies (for pooled and between-farms models). Asterisks denote statistical significance at: * p<0.1, ** p<0.05, *** p<0.01.

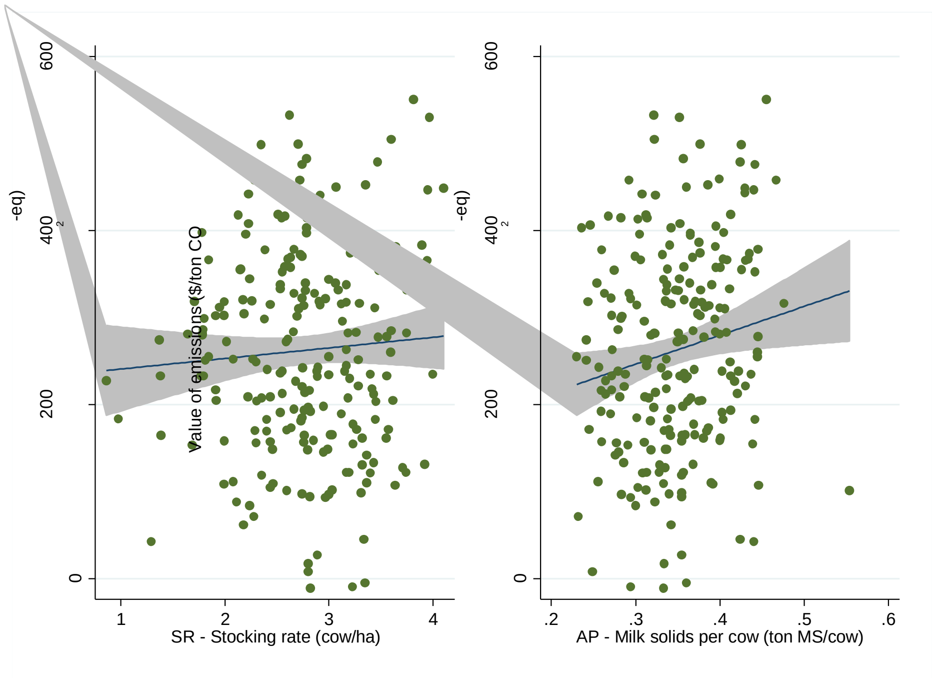
To provide more insights to this discussion, but from a different angle, the next section analyses the relationship of AP and SR with the “value of emissions” on a farm.

[14] Fertiliser is not included here or in previous regressions because data are available for only 69 observations.

4 Value of emissions

We now explore the impact of the mitigation options AP and SR on the economic value farms generate from each unit of emissions. This addresses the question of where emission reductions would likely be highest cost. We define the "value of emissions" as COS/ton CO_2eq. Figure 5 suggests that there is wide variation in the value of emissions at all levels of SR and MS per cow, but that neither SR nor AP has a clear relationship with the value of emissions. However, other factors that affect value could obscure a relationship, so we test this in a regression.

Figure 5: Value of emissions and mitigation options



Note: The grey area shows 95% confidence-interval for regression lines.

Table 6: Value of emissions (cash operating surplus per ton of greenhouse gases) and mitigation options

	Pooled model	Between model	Within model
Stocking rate	18.077	25.228*	44.322
	(12.239)	(13.533)	(38.784)
Milk solids per cow (AP)	521.149***	552.678***	433.731
	(125.292)	(153.963)	(265.542)
Use of irrigation	5.372	-33.947	-86.839
	(20.340)	(48.315)	(107.198)
Use of feed pad	-10.031	-10.035	-24.276
	(13.800)	(18.520)	(46.711)
Use of DCD	29.092	2.647	61.385
	(24.243)	(26.149)	(44.640)
Hay and silage feed expenses per cow	-0.267***	-0.253***	-0.236*
	(0.052)	(0.070)	(0.126)
Animal health expenditure per cow	-0.577***	-0.398	-1.010
	(0.187)	(0.264)	(0.648)
Depreciation per cow	0.036*	0.018	0.098**
	(0.019)	(0.020)	(0.043)
Number of supplements imported	11.346***	11.184**	3.435
	(3.878)	(5.465)	(9.306)
Log of total effective area	-36.869**	-27.495	112.846
	(15.224)	(18.548)	(104.775)
Constant	293.845**	219.703	-215.889
	(134.707)	(182.522)	(765.862)
Number of observations	222	144	135
R-squared	0.712	0.685	0.815

Notes: Robust standard errors are in parentheses. Additional controls, not reported here, include rainfall, temperature, topography (dummy variables for easy hill, rolling hill and steep hill), soil type (dummy variables for peat, podzol, pumice, recent YGE, sands and volcanic) and regional dummies (for pooled and between models). Asterisks denote statistical significance at: * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

The results provided in Table 6 show that there is no statistically significant association between SR and the value of emissions, except in the between-farms model, where the positive coefficient is barely significant at the 10% level. Across all observations (pooled model) and farms (between-farms model), those with higher MS per cow achieve higher value for each ton of emissions. This is consistent with our other results.

5 Implications for no-cost and lowest-cost mitigation

Our results suggest that improving AP strongly reduces emissions intensity, and that lowering SR, while lowering absolute emissions, comes with a loss of profit per hectare. Is the combination of high AP with low SR a no-cost absolute mitigation option? What do our results suggest about the lowest-cost way to achieve absolute emission reductions? Might it be better to maintain higher SRs but convert some dairy farms to low-emission uses? To explore the implications of changes in AP, SR and land-use change for absolute emissions and profits for farms, and for the sector as a whole, we ran four "experiments" using our data and the results from the regression models.

The first experiment explored what would happen with an increase in AP alone. We increased AP by one standard deviation (approximately 60 kg of additional MS per cow; see Table 1) across all 222 farm observations. After adjusting for the gains in emissions intensity obtained, the absolute GHG emissions per farm, on average, increase by 246.79 tons of CO_2eq, or 1.6 tons of CO_2eq per hectare. The increase in AP would also mean $95,600 extra profit on the average farm, or an additional $618 per hectare.

Our other experiments then simulated three alternative ways to reduce absolute emissions, so that, combined with the increase in AP (and related increase in absolute emissions), absolute emission levels are unaffected. If this can be done with an increase in profit, then the mitigation option is likely to be no cost. The three mitigation approaches we explored are:

(i) reduce SR on all farms;
(ii) close a random selection of farms (i.e. average performance); and
(iii) close the most inefficient farms (in terms of lowest value of emissions (COS/ton of GHG)). We applied each approach until we offset the extra GHGs emitted in the system from the increase in AP.

In our second experiment, case (i), a reduction of SR increased the emissions intensity of the farm (ton GHG/ton MS). Taking account of this effect, to mitigate the extra GHGs emitted by the increase in AP, we would need to reduce average SR from the current level of 2.78 cows per hectare to only 2.34 cows per hectare. This reduction would imply a loss in profit of around $61,000 per farm, or $397 per hectare.

For case (ii), given that with higher AP the average farm in our sample emits 1,844 tons of CO_2eq, reducing emissions to original levels would require the closure of 13% of all farms. This would bring an average profit loss across the farm system of $443 per hectare.

For case (iii), if we target the least-efficient farms (those with the lowest initial value of emissions), 12% of farms would need to be closed to offset the extra GHGs emitted. In this case, the average profit loss across the farm system would be $174 per hectare.

Raising AP in combination with a reduction in SRs may hold absolute emissions constant, with an increase in profit of around $220 per hectare. This implies that absolute emissions could be reduced at no cost. However, even without considering the economic opportunity of doing something else on the farmland that is retired from dairy, closing the least-efficient farms seems an even lower-cost way to reduce absolute GHGs. Combining higher AP with a reduction in the number of inefficient farms could hold absolute emissions constant and provide a dividend of $444 on the average hectare of existing farmland, as well as free up 12% of dairy land for other uses. This suggests that absolute emissions could be reduced even more at no cost with this combined option. If the land has alternative potential uses, even closing farms with average performance seems likely to be a cheaper way to reduce absolute emissions.

The combination of facilitating greater uptake of high-performance animals, maintaining SRs on efficient farms and converting some of the less efficient farms to alternative land uses seems to be worth close consideration for reducing absolute biological emissions from the dairy sector at low cost.

6 Conclusion

Using the NZMFD, this paper contributes to the limited empirical literature employing cross-sectional farm-level data in New Zealand (e.g. Anastasiadis & Kerr 2013; Jiang & Sharp 2014, 2015; Soliman & Djanibekov 2018). In particular, it explores the efficacy of two mitigation options to reduce biological GHG emissions on farms: reducing the SR (number of cows per effective hectare of dairy land); and increase AP (measured by production of MS per cow). These mitigation options have been explored in numerous agricultural scientific papers as options that, if applied together, could reduce the carbon footprint of farms while also maintaining or even improving profits (e.g. de Klein & Dynes 2017). Using existing variability across and within actual farms, we explore the impacts that these options might have on emissions intensity, absolute emissions and farm profitability.

We evaluate the effect of these mitigation options on four main variables: milk profitability of the farm (COS/ton of MS produced), profit per hectare (COS/effective hectare), emissions intensity (ton CO_2eq/ton of MS produced) and the value of emissions (COS/ton CO_2eq). By investigating these mitigation options and the characteristics of farms, we find two patterns.

First, farms with higher AP (measured as MS per cow) are over-represented in the group of “efficient” farms with low emissions intensity and high profits. This relationship is confirmed in the regression results, with high-AP farms having significantly lower emissions intensities and higher profits (both COS per ton of MS and per hectare), and achieving higher profits per unit of GHGs emitted. This appears to be a strong no-cost option to mitigate emissions intensity. An increase in MS per cow by one standard deviation (60 kg) could lead to $17 more profit per ton of GHGs, an increase in profit of $618 per hectare but also an increase in GHGs of 1.6 tons per hectare.

Second, farms with high SRs are also over-represented in the group of “efficient” farms and, like high-AP farms, this result is confirmed in the regressions. A higher SR is significantly associated with a lower emissions intensity of the farm, is not significantly associated with milk profitability (COS per ton of MS), but is positively associated with profit per hectare. It is mostly not significantly associated with the value per unit of GHGs. However, AP is correlated with high SR, which could lead to multicollinearity bias in our estimates.

Given these findings, can we claim that the combination of low SR and high AP could be an effective option to mitigate GHGs and maintain (or improve) profits on the farm? Higher levels of AP clearly seem to reduce the GHG intensity of the farm and increase profit – a "no-cost" option. However, unless either the SR or the area of dairy farming fall, an increase in MS per cow (AP) will lead to an increase in absolute emissions. We test this by checking how much it would cost to mitigate the extra total emissions that an increase of one standard deviation of AP could bring. Mitigating emissions would cost \$397 per hectare if SR is reduced, or around \$174 per hectare if farms with the lowest "value of emissions" (profits generated per unit of GHG) are removed from dairy production in our sample. Both values are lower than the profits that would be generated by the increase in AP (\$618 per hectare).

Thus, combined, the two options – low SR and high AP – do seem to constitute a no-cost combination. However, potentially the same mitigation could be achieved with lower loss of profit by reducing the area of dairy land through encouraging changes in land use on the least-efficient farms, while at the same time maintaining high SRs and increasing the AP on the remaining dairy land.

In conclusion, this paper is an important initial empirical attempt to assess the effect of two potential mitigation options (low SRs and high AP) on the emissions intensity, milk profitability and value of emissions of farms using farm-level data. Previous analysis of this issue has used modelling or very small numbers of pilot farms, and not data on the behaviour of actual farmers. Although our results are only indicative, they suggest that recommendations developed using farm modelling and careful science might not translate well when applied to real farms.

This illustrates a strong need to develop better-quality longitudinal farm-scale data, collected on the same farms over many years (to account for the effects of variation in milk payouts and weather). A randomly selected, statistically balanced, longitudinal dataset with high-quality emission estimates, accurate measures of farm practices related to mitigation, and financial data – and, even better, the use of randomised control trials structured to assess financial impacts as well as emission impacts – could generate robust estimates of the true cost of proposed mitigation options.

References

Anastasiadis, Simon, and Suzi Kerr. 2013. "Mitigation and Heterogeneity in Management Practices on New Zealand Dairy Farms." *Motu Working Paper 13-11*. Motu Economic and Public Policy Research Trust, Wellington, New Zealand.

Davidson, R. and M. Newman. 2017. "Key Drivers of GHGs on NZ Dairy Farms". Paper presented at the New Zealand Agricultural and Resource Economics Society (NZARES) Conference, 19–20 October 2017, Rotorua, New Zealand.

de Klein, Cecile, and Robyn Dynes. 2017. "Analysis of a New Zealand-specific No-cost Option to Reduce Greenhouse Gas Emissions from Dairy Farms." AgResearch report prepared for Motu Economic and Public Policy Research Trust, Wellington, New Zealand. Available online at https://motu.nz/our-work/environment-and-resources/agricultural-economics/no-cost-barriers/analysis-of-a-new-zealand-specific-no-cost-option-to-reduce-greenhouse-gas-emissions-from-dairy-farms. Last accessed 14 May 2019.

Henry, Loïc, Edmund Lou and David Fleming. 2017. "New Zealand Monitor Farm Data." *Motu Technical Paper*. Motu Economic and Public Policy Research Trust, Wellington, New Zealand. Available online at http://motu.nz/assets/Uploads/MAF-Monitor-Farm-Data.pdf. Last accessed 14 May 2019.

Jiang, Nan, and Basil Sharp. 2014. "Cost Efficiency of Dairy Farming in New Zealand: A Stochastic Frontier Analysis", *Agricultural and Resource Economics Review*, 43:3, pp. 406–18.

———. 2015. "Technical Efficiency and Technological Gap of New Zealand Dairy Farms: A Stochastic Meta-Frontier Model", *Journal of Productivity Analysis*, 44:1, pp. 39–49.

Macdonald, K. A., J. W. Penno, J. A. Lancaster and J. R. Roche. 2008. "Effect of Stocking Rate on Pasture Production, Milk Production, and Reproduction of Dairy Cows in Pasture-based Systems," *Journal of Dairy Science*, 91:5, pp. 2151–63.

Ministry for the Environment. 2018. *New Zealand's Greenhouse Gas Inventory 1990–2016*. Wellington: Ministry for the Environment. Available online at http://www.mfe.govt.nz/publications/climate-change/new-zealands-greenhouse-gas-inventory-1990%E2%80%932016. Last accessed 14 May 2019.

Ministry of Agriculture and Forestry. 2010. *Farm Monitoring Overview*. Wellington: Ministry of Agriculture and Forestry.

Reisinger, Andy, and Harry Clark. 2016. "Modelling Agriculture's Contribution to New Zealand's Contribution to the Post-2020 Agreement." MPI Information Paper No: 2016/02.

Reisinger, Andy, Harry Clark, Ross Abercrombie, Mark Aspin, Peter Ettema, Mark Harris, Andrew Hoggard, Matthew Newman and Greg Sneath. 2018. "Future Options to Reduce Biological GHG Emissions On-farm: Critical Assumptions and National-scale Impact." New Zealand Agricultural Greenhouse Gas Centre report to the Biological Emissions Reference Group (BERG). Available online at https://www.mpi.govt.nz/dmsdocument/32128/send. Last accessed 14 May 2019.

Shepherd, Mark, Adam Daigneault, Brent Clothier, Brian Devantier, Sandy Elliott, Suzie Greenhalgh, Duncan Harrison et al. 2016. "New Zealand's Freshwater Reforms: What Are the Potential Impacts on Greenhouse Gas Emissions?" *Motu Note 26*. Motu Economic and Public Policy Research Trust, Wellington, New Zealand. Available online at https://motu.nz/assets/Documents/our-work/environment-and-resources/climate-change-mitigation/agricultural-greenhouse-gas-emissions/Freshwater-and-GHGs.pdf. Last accessed 14 May 2019.

Soliman, Tarek, and Utkur Djanibekov. "Assessing Dairy Farming Eco-efficiency in New Zealand: A Two-stage Data Envelopment Analysis." Paper presented at the Agricultural and Applied Economics Association Annual Meeting, 5–7 August 2018, Washington, DC.

Wheeler, D. M., S. F. Ledgard, and C. A. M. DeKlein. 2008. "Using the OVERSEER Nutrient Budget Model to Estimate On-farm Greenhouse Gas Emissions", *Australian Journal of Experimental Agriculture*, 48:2, pp. 99–103. Available online at https://doi.org/10.1071/EA07250. Last accessed 14 May 2019

Appendix A: Replication of results considering farm profits before tax (FPBT) instead of cash operating surplus (COS)

Table A1: Emissions intensity (ton of greenhouse gas per ton of milk solids) and milk profitability (cash operating surplus per ton of milk solids) models, considering FPBT instead of COS

	Pooled model		Between model		Within model	
	Emissions intensity	Milk profitability	Emissions intensity	Milk profitability	Emissions intensity	Milk profitability
Stocking rate	-1.110***	-101.212	-1.233***	-42.017	-0.218	297.765
	(0.157)	(107.850)	(0.184)	(122.346)	(0.222)	(205.884)
Milk solids per cow (AP)	-13.475***	7,450.347***	-11.062***	8,552.312***	-22.476***	3,106.187**
	(1.692)	(1,165.897)	(2.096)	(1,393.641)	(1.521)	(1,404.071)
Use of irrigation	0.184	64.618	0.153	-378.120	2.098***	-429.066
	(0.545)	(375.396)	(0.658)	(436.960)	(0.614)	(576.333)
Use of feed pad	0.079	-0.363	-0.040	-9.956	-0.645**	-402.317
	(0.221)	(151.418)	(0.252)	(167.211)	(0.268)	(251.146)
Use of DCD	-0.673**		-0.646*		-0.710***	
	(0.297)		(0.356)		(0.255)	
Hay and silage feed expenses per cow	-0.001	-3.141***	-0.001	-3.032***	0.000	-2.572***
	(0.001)	(0.516)	(0.001)	(0.633)	(0.001)	(0.649)
Animal health expenditure per cow	-0.001	-5.281***	-0.003	-4.630**	0.014***	-7.491**
	(0.003)	(2.035)	(0.004)	(2.285)	(0.004)	(3.484)
Depreciation per cow	0.001***	-2.452***	0.001***	-2.597***	-0.001***	-2.067***
	(0.000)	(0.159)	(0.000)	(0.179)	(0.000)	(0.230)
Number of supplements imported	-0.053	90.895**	-0.049	93.571*	-0.023	34.897
	(0.058)	(39.992)	(0.074)	(49.286)	(0.053)	(50.033)
Log of total effective area	-0.063	-402.715***	-0.260	-375.954**	0.274	1,215.437**
	(0.216)	(148.552)	(0.253)	(167.460)	(0.600)	(563.230)

	Pooled model		Between model		Within model	
	Emissions intensity	Milk profitability	Emissions intensity	Milk profitability	Emissions intensity	Milk profitability
Constant	14.678***	3,005.678**	14.532***	2,411.796	18.500***	-626.962
	(2.031)	(1,399.626)	(2.485)	(1,645.092)	(4.381)	(4,112.148)
Number of observations	222	222	144	144	135	135
R-squared	0.660	0.784	0.679	0.803	0.955	0.947

Notes: Standard errors are in parentheses. Regressions are conducted with additional controls, including rainfall, temperature, topography (dummy variables for easy hill, rolling hill and steep hill), soil type (dummy variables for peat, podzol, pumice, recent YGE, sands and volcanic) and regional dummies (for pooled and between-farms models). Asterisks denote statistical significance at: * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A2: Value of emissions considering FPBT (FPBT per ton of greenhouse gas) instead of COS

	Pooled model	Between model	Within model
Stocking rate	1.653	5.892	41.399
	(11.822)	(12.615)	(37.141)
Milk solids per cow (AP)	785.558***	842.734***	550.539**
	(113.923)	(143.517)	(254.293)
Use of irrigation	-2.109	-39.025	-68.515
	(19.249)	(45.037)	(102.657)
Use of feed pad	-9.593	-10.158	-42.278
	(13.187)	(17.264)	(44.732)
Use of DCD	18.141	-6.169	50.497
	(21.866)	(24.375)	(42.749)
Hay and silage feed expenses per cow	-0.277***	-0.266***	-0.259**
	(0.050)	(0.066)	(0.120)
Animal health expenditure per cow	-0.567***	-0.428*	-0.892
	(0.176)	(0.246)	(0.621)
Depreciation per cow	-0.219***	-0.233***	-0.169***
	(0.017)	(0.018)	(0.041)
Number of supplements imported	10.097***	10.034*	4.997
	(3.753)	(5.094)	(8.912)
Log of total effective area	-41.868***	-34.929**	114.086
	(14.392)	(17.290)	(100.337)
Constant	237.120*	157.327	-297.757
	(128.616)	(170.138)	(733.418)
Farm fixed effects?	No	No	Yes
Number of observations	222	144	135
R-squared	0.797	0.808	0.819

Notes: Standard errors are in parentheses. Regressions are conducted with additional controls, including rainfall, temperature, topography (dummy variables for easy hill, rolling hill and steep hill), soil type (dummy variables for peat, podzol, pumice, recent YGE, sands and volcanic) and regional dummies (for pooled and between-farms models). Asterisks denote statistical significance at: * p<0.1, ** p<0.05, *** p<0.01.

Appendix B: Comparison between efficient and non-efficient farms for additional variables

Table A3: Efficient and non-efficient farms by continuous management practice for additional variables

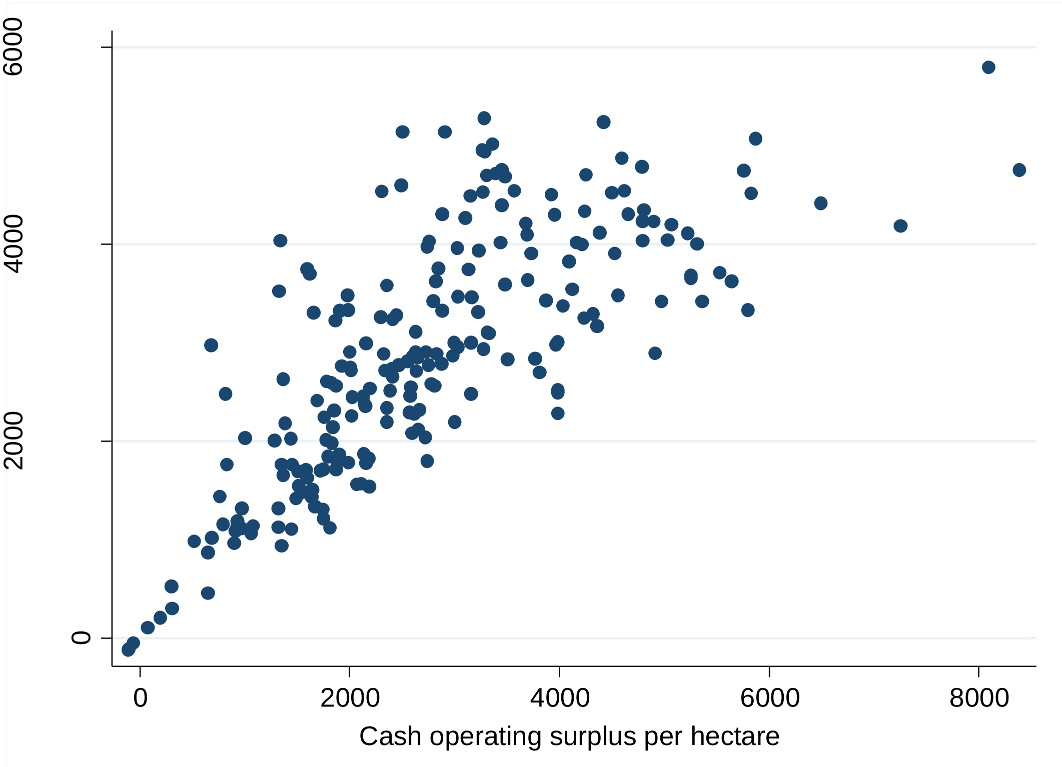
	Farms		t-test	Wilcoxon rank-sum test
	Efficient (n = 57)	Non-efficient (n = 165)		
Cash surplus/deficit per hectare	790.4354 (228.746)	89.4879 (134.037)	-2.644**	-2.663**
Revised stocking unit	4,020.73 (326.11)	3,489.19 (161.59)	-1.461	-1.984**
Total farm working expenditure per kilogram of milk solids	3.475 (0.094)	4.083 (0.077)	5.001***	3.781***
Vehicle R&M per cow	30.7307 (3.0626)	41.570 (2.330154)	2.817***	2.407**
Vehicle R&M per kilogram of milk solids	0.084 (0.008)	0.127 (0.008)	4.018***	2.955***
Cash operating surplus per hectare	3730.742 (238.252)	2496.265 (132.9048)	-4.525***	-4.602***
Cash operating surplus (% net cash income)	0.471 (0.011)	0.378 (0.013)	-4.364***	-3.458***
Cattle sales	78,301.05 (6,229.968)	58,224.92 (3201.214)	-2.866***	-3.344***
Farm profit before tax (%net cash income)	0.222 (0.028)	0.111 (0.020)	-3.169***	-2.710***
Net cash income per cow	2,580.413 (1,036.788)	2,272.48 (74.971)	-2.407**	-3.259***
Net cash income per hectare	7,745.683 (366.1656)	6,278.581 (228.832)	-3.398***	-3.787***
Other administration costs per cow	6.415 (1.058)	12.37161 (1.67675)	3.005***	2.392**
Total farm working expenditure (% net cash income)	0.529 (0.017)	0.622 (0.013)	4.364***	4.458***

Notes: All variables are available for all 222 observations. Standard deviations are in parentheses. Asterisks denote statistical significance of test at: * p<0.1, ** p<0.05, *** p<0.01. The t-tests conducted here are those of two samples with unequal variances.

Appendix C: Profits (cash operating surplus COS)) per hectare relative to milk profitability ((COS) per kilogram of milk solids)

The correlation of COS/ton of MS and COS/ha is 0.757 (significant at the 1% level) and can be observed in Figure A1.

Figure A1. Correlation between cash operating surplus per kilogram of milk solids and cash operating surplus per hectare



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