Identifying barriers to adoption of "no-cost" greenhouse gas mitigation practices in pastoral systems

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Abstract

New Zealand scientists have suggested that multiple pastoral farming practices could reduce on-farm biological greenhouse gas (GHG) emissions while maintaining (and in some circumstances even increasing) farm profits (e.g. de Klein and Dynes, 2017). However, these win–win practices (which we define as "no-cost" mitigation practices) are reported to be under-adopted in New Zealand (Reisinger et al. 2018). The focus of this paper is to identify barriers affecting the adoption or expansion of no-cost mitigation practices by farmers in New Zealand. We define and categorize barriers to adoption using a typology of barriers developed by Jaffe (2017). This typology provides a comprehensive list and precise/accurate description of multiple barriers that might be present in farming contexts. First, we confront the typology with empirical evidence in the literature studying the barriers to the adoptions of technologies and practices in the context of pastoral farming. Although the evidence on perceptions and adoption of GHG emissions mitigation options in New Zealand is very limited, several of the barriers in Jaffe's typology have been evidenced by researchers as affecting the decisions to adopt different innovative technologies and practices on farms.

To complement the literature review and, more importantly, focus on no-cost GHG mitigation practices, we conducted interviews with 14 farmers in different regions of the country. In these conversations we discussed different managerial and practical implications of five different no-cost farming practices, with the aim of identifying barriers that affect their adoption or expansion. We describe in the paper more than 40 quotes obtained from farmers, from which we identified the occurrence of 16 different barriers. Among these, the "Unsureness about practicality", "risk and uncertainty" and "complex interactions" barriers showed as the most frequent barriers identified as causing under-adoption of the evaluated practices. In addition, different types of perceived costs (financial barriers), such as "modelling mismatch" and "learning and adjustment", have been pointed out as a limitation for adoption (which are captured by barriers category "arguably efficient" in Jaffe's typology). We also found that in some cases non-financial barriers seem to be interconnected – in especial the case when the interactions' complexity increases the riskiness of the outcome (the "risk and uncertainty" barrier) and makes it difficult to see whether the mitigation option is practical (a barrier of "unsureness about practicality").

We expand our analysis to the identification of barriers on other practices that have not been necessarily defined as no-cost. Namely, the use of dairy bobby calves in the sheep and beef industry and once a day milking. Finally, we also recorded quotes from farmers regarding their direct perception of the different barriers from Jaffe's typology. This complements our analysis with comments from farmers with respect to implications of the multiple barriers investigated.

Our findings are relevant because they not only point out the need for further research to investigate the no-cost status of different practices in different contexts, but also highlight different non-financial barriers that directly affect the adoption of mitigation practices. Identifying these barriers is key for future policy planning and GHG mitigation research, as, with clearer signals and incentive mechanisms, policy can better inform the decision-making of farmers, therefore reducing on-farm GHG emissions throughout New Zealand.

JEL codes
Q10; Q19; Q52; Q54

Keywords
Barriers to adoption; GHG mitigation practices; pastoral systems; climate change

Summary haiku

Raise awareness of
practices that mitigate
on farms at no cost.

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Tables and Figures

1 Introduction

Given increasing societal concerns over the consequences of climate change, the New Zealand government has, over the last decade, increasingly funded programmes and research aimed at evaluating whether and to what extent different farming practices can support the mitigation of on-farm greenhouse gas (GHG) emissions. Thus, several farming practices have been identified as viable options to reduce emissions across farms. In addition, New Zealand scientists have stated that some of these mitigation practices can maintain, and in some circumstances even increase, farm profits. These win–win practices, capable of reducing GHG emissions and at the same time sustaining economic viable pastoral systems, are defined as "no-cost" practices in our study.[1] Although many of these no-cost practices are common in pastoral systems and are generally applied across regions, government reports have established that they are "under-adopted", as they could be applied more than is currently the case (Reisinger et al. 2018). This is a conundrum, as – at least theoretically – it is economically inefficient for farmers to not adopt these practices, which could both reduce emissions and increase farm profits. The causes of this low adoption of no-cost practices are investigated in this paper through the identification of non-financial barriers to farmers' decision-making.

Identifying barriers to the adoption of no-cost mitigation practices is key for future policy planning and GHG mitigation research. With better knowledge of their effect on farmers' decision-making with regards to no-cost practices, better communication and incentive mechanisms can be developed to reduce barriers and achieve a higher uptake of these practices and, consequently, reduce GHG emissions throughout New Zealand.

Our identification of non-financial barriers is theoretically grounded in the typology of barriers to adoption developed by Jaffe (2017).[2] This typology lists 29 different barriers, which we grouped in seven categories and summarise in Section 2. To identify barriers to adoption, we apply two research methods in this paper: a comprehensive literature review of agricultural adoption; and the development of interviews with 14 farmers across the country. The interviews explored different managerial and practical implications of five common farming practices that are reported to be "no cost" in New Zealand (de Klein and Dynes 2017):

- Reduced stocking rate and/or high breeding worth cows (Dairy)
- Reduced replacement rates (Dairy)
- Reduced N fertiliser use/replacing some pasture with lower N feed (Dairy)

[1] Thus, formally, no-cost mitigation practices or options are those whose adoption reduces the farm's GHG emissions and does not reduce (and may increase) the profitability of the farm (Jaffe 2017).
[2] We claim that these are "non-financial" barriers because, given that we are looking at no-cost mitigation practices, the financial component of implementing these practices would not be relevant to the decision made by the farmer, as the current profit levels of the farm would not be reduced. Thus, other barriers, beyond costs, should be in place to explain under-adoption.

- Increased scanning percentage (Sheep and beef)
- Increased live-weight gain in lambs (Sheep and beef)

From the literature review, we found few studies looking at adoption related issues to GHG mitigation practices or options in New Zealand (Harmsworth et al., 2010; Niles et al., 2016), so we expanded our review to adoption of any new practices in agricultural activity in New Zealand and Australia.[3] We found evidence that many of the barriers proposed by Jaffe's (2017) typology have been identified across contexts. Notably, the barriers of "awareness" and "risk and uncertainty" have been more commonly discussed across studies. In contrast, we could find no evidence of studies looking at or identifying a handful of barriers, especial those from the typology category "Regulation and policy".

In order to explore in depth the potential occurrence of barriers related to the adoption of no-cost practices within the NZ context, we conducted ten interviews with dairy farmers and four with sheep and beef farmers in different regions. The aim of the interviews was to discuss different managerial and practical implications of no-cost practices, and to deduce from these conversations the presence of barriers.[4] As mentioned, we focused our barrier identification analysis on five different no-cost practices. An initial finding is that while all farmers were familiar with these practices, the majority were not aware that the practice could contribute to reduce on-farm GHG emissions. In other words, awareness was not a barrier from the productive point of view, but it was from an environmental management angle, as most farmers did not know that the further use of these practices could importantly reduce the carbon footprint of their operations –a lack of "mitigation awareness".

From the analysis of the interviews with farmers, we recorded more than 40 quotes about implications of the five no-cost practices (reported in detail in Tables 3-7), from which we identified the occurrence of 17 different barriers. Three barriers that were identified in multiple occasions can be considered as financial limitations to adoption: "modelling mismatch" (the case when the practice does have higher operational costs than benefits), "variable farming landscape" (the previous case, but just in the context of particular farms), and "learning and adjustment" (when the learning process is too expensive). These three barriers belong to the category "arguably efficient" of Jaffe's typology. Of these three, the most important in our analysis was modelling mismatch, which was identified six times, four of them in the practice "low stocking rate and high breeding worth cows" (SR/BW), one in "reduce replacement rate" and one in "Increase live-weight gain in lambs". This result points out that, for at least some farmers, these practices (in special SR/BW) are perceived to have a financial cost, and this constrains their further adoption. This implies that farmers expect more evidence of the

[3] We included Australia in the review to expand the evidence on barriers to adoption.
[4] Beyond the decision of whether or not to adopt a particular practice, farmers generally also face the decision of how much (expand or reduce) to apply the practice.

profitability-enhancement potential of some no-cost practices in different scenarios, so as to be more aware of their costs and benefits in specific contexts. This is relevant, because no-cost practices are commonly assessed by engineering–economic analyses that quantify the costs and benefits of different options using a combination of data, models, and other tools that often miss the heterogeneous complexities of different contexts (Jaffe, 2017).[5] This seems to explain why these barriers (from the category of "arguably efficient" barriers category) are particularly relevant in our findings: some options deemed "no cost" are not being further adopted, in part as a consequence of perceived associated costs.

We also found that the non-financial barriers "complex interactions" and "inadequate managerial capability" were relevant in our analysis. The former was identified eight times across three different practices, while the latter was identified four times in three practices.[6] Complexity interactions is an information barrier (farmers are not sure how well the practice would mesh well with other farm processes), while inadequate managerial capability is defined by Jaffe as a behavioural barrier (lack of skills perceived by the farmer to comprehensively manage the practice). In both cases the barriers were identified from farmers' quotes justifying no further use of the practices because of their increasing difficulty, skills-necessity and managerial stress.

Among the investigated no-cost practices, "SR/BW" received the largest number of non-financial barriers to adoption –15 different ones. This finding points out that this practice is embedded with multiple factors that affect the decision-making of farmers from different angles, precluding the further use of this in New Zealand agriculture. On the other hand, the practice "Reduced N fertiliser use/replacing some pasture with lower N feed" received the lowest number of barriers in our analysis (only one), suggesting that the implementation of this no-cost practice should be less affected by non-financial barriers than the rest. In addition to the six no-cost practices, we also expanded our analysis to the identification of barriers for other practices that are not necessarily win-win options. Namely: the use of dairy bobby calves in the sheep and beef industry and the adoption of a "once a day milking" system. In these cases we found that barriers in the typology category of "Market structure and institutions" are more relevant than in the analysed no-cost practices (quotes and barriers listed in Table 8). Finally, we also recorded quotes from farmers with respect to their impressions on the list of barriers in the typology, which complement our analysis with insights from farmers with respect to implications of the multiple barriers (Table 9).

The remainder of the paper is structured as follows. Section 2 lists and describes the potential barriers that might affect the adoption of mitigation practices by farmers, based on Jaffe (2017), and reviews the agricultural New Zealand and Australian literature exploring some

[5] For instance, considerations that are economically relevant to farmers of a region, or of a particular type of farming, might have been ignored in modelling.
[6] Frequency of all barriers, per practice, are summarised in Table 11 of section 6.

of these barriers. Section 3 describes and discusses the five no-cost mitigation practices used in the interviews of this paper. Section 4 describes the interview methodology. Section 5 analyses the interview data and identifies non-financial barriers affecting the further adoption of no-cost practices. This section also provides an analysis of barriers to the implementation of other mitigation practices and the farmers' perceptions of the list of barriers in Jaffe's (2017) typology. Section 6 discusses the results and implications of the findings and methodologies for policy and future research, as well as other considerations to take into account. Finally, Section 7 concludes the paper.

2 Potential barriers to adoption

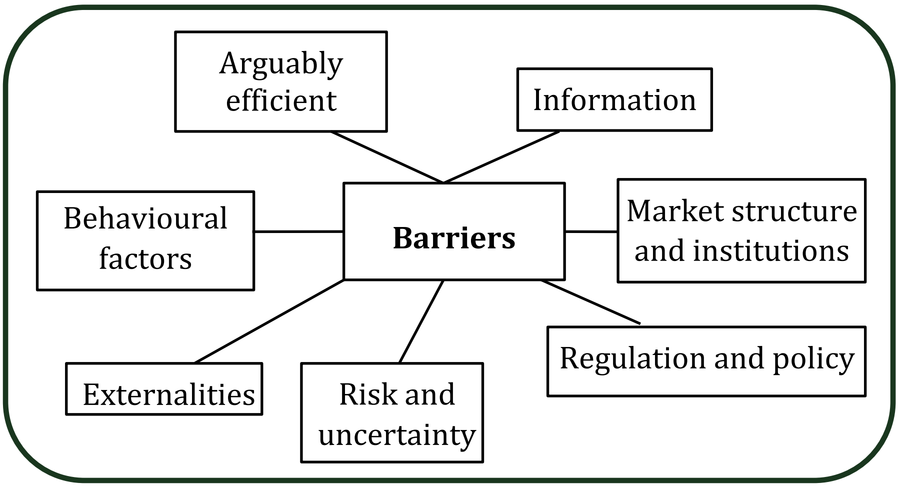
Jaffe (2017) proposes a typology to identify and classify factors or barriers, other than expected profitability, that can affect farmers' decisions on the adoption of farming practices or technologies. He identified seven broad categories, based on the economics, psychology, and sociology literatures. The typology particularly draws on evidence found in the broader economics literature on barriers to technology adoption. These barriers can discourage land-use change and the adoption of new known practices in agriculture or the intensive use of these, therefore reducing a farmer's willingness to apply a no-cost mitigation option.

Figure 1 shows the seven categories of barriers. "Arguably efficient" barriers are those where an option can pass a cost–benefit analysis but this simple financial profitability test fails to measure correctly the true impact of the adoption in a specific case, thus meaning that the option is not truly no cost. "Information" barriers relate to awareness or imperfect availability of information, which affect a farmer's decision-making. "Market structure and institutions" barriers refer to situations where market or institutional failures inhibit adoption. "Regulation and policy" barriers are those resulting from the lack of clarity from policy signals, in the form of regulation or incentives (lack of clarity arising either from the absence of policies or multiple conflicting policies, for instance). "Risk and uncertainty" barriers relate to potential new, unfamiliar options/practices that might involve more risk and/or uncertainties from the perspective of the farmer.[7] "Externalities" are barriers where the costs and/or (especially) benefits of adopting the mitigation practices are not borne by the farmer/decision-maker, thereby reducing his or her incentive to adopt. Finally, "behavioural factors" include different

[7] Risk and uncertainty surrounding future outcomes associated with new technologies or practices may lead to real or apparent barriers to adoption of no-cost options. However, it is important to clarify here that in economic theory, risk is different from uncertainty: while risk relates to outcomes that are governed by some probability distribution, uncertainty is given by outcomes that are unknown or where the probabilities of different outcomes are unknown. Since some scholars prefer to combine these two terms in the agricultural literature (e.g. Abadi Ghadim et al. 2005), we group them as one barrier. Thus, when using the barrier "risk and uncertainty", we mean risk aversion together with uncertainty (or ambiguity) aversion. It is easy to predict that a risk-loving or uncertainty-loving farmer would adopt any option if he or she sees some future benefits, even if these are small.

types of barriers related to biases and perceptions shaped by culture or traditional ways of doing things.

Figure 1. Categories of barriers to efficient decision-making in farming contexts.



Source: Dorner et al. (2018).

Table 1 details all the barriers included in each category, as described in Jaffe (2017), and provides definitions from both technical and non-technical points of view.[8] The latter definition was used in the interviews conducted with farmers in the study.

As shown in Table 1, the barriers "risk and uncertainty" and "externalities" do not have sub-categories but each constitutes a category and a barrier in itself.[9] In contrast, the "behavioural factors" category includes the largest number of sub-categories, these constituting the different cognitive barriers that people (broadly speaking, not just farmers) face when making decisions.

2.1 Evidence in the Literature

The international literature on adoption of farming practices and/or technologies in agriculture is vast and numerous. However, studies of barriers to adoption of mitigation practices are still at the early stages, especially in New Zealand. Given this limited evidence on mitigation options in the New Zealand context, we expanded our review to studies looking at the adoption of agricultural practices in general. Owing to the vicinity and cultural similarities between New Zealand and Australia, we complemented our analysis with studies from the Australian context.

In addition to detailing barriers, Table 1 lists the references for studies that identify the existence of the respective barriers within the context of New Zealand or Australian farming. A brief discussion of the referenced papers is provided in Appendix 1. Appendix 2 provides similar

[8] Barrier names shown here differ slightly from those used in Jaffe (2017).
[9] However, as mentioned in the notes to the table, these barriers are indeed decomposed in Jaffe's (2017) typology; despite this, we decided to separate them into two to simplify the interview analysis.

information, but focusing on the Māori context in New Zealand – literature mostly linked with governance issues about land-use change decisions. This Māori-context literature is identified in Table 1 with a superscript "M" after the respective reference. A list of selected international studies looking at barriers to adoption in general is available online.[10]

The fourth column of Table 1 also shows those cases where a particular barrier according to Jaffe's (2017) typology was not found in the literature; these instances are indicated by "N/F". However, we cannot claim that the non-evidenced barriers (the N/F barriers) in the literature are not, in fact, relevant to New Zealand agriculture as it could be product of research oversight. This gap in knowledge is, to some extent, filled with the interview work we conducted for this paper, from the context of the adoption of no-cost mitigation practices.

[10] Available at https://motu.nz/our-work/environment-and-resources/agricultural-economics/no-cost-barriers/database-of-evidence-on-barriers-to-adoption-in-agriculture-in-new-zealand-and-overseas/.

Table 1. Barriers for the adoption of farm practices or options.

Barrier	Technical definition	Non-technical definition	Evidence in the scientific literature*
1. Arguably efficient			
1.1 Modelling mismatch	Barrier arisen from incorrect assumption in modelling	The practice does have greater costs than benefits!	Doole & Kingwell (2015), Harmsworth et al. (2016)[M]
1.2 Option value	A "value" of waiting to get a lower price	I'll try it one day, but not yet	N/F
1.3 Variable farming landscape[A]	The possibility that a no-cost option works for some farms but not others due to heterogeneity	The model doesn't reflect the landscape of my farm	Bewsell & Kaine (2005), Doole & Kingwell (2015)
1.4 Learning and adjustment	If adaptation costs are high enough or the learning period is long enough, the eventual benefit may not justify bearing these costs	It pays off only once we have learnt how to do it, but the learning process is too expensive	De Silva & Forbes (2016), Abadi Ghadim et al. (2005), van Reenen (2012)
2. Information			
2.1 Awareness	Farmers are not aware of the existence of no-cost options	We just didn't know	Rhodes et al (2002), Harmsworth et al. (2010)[M], Cary & Wilkinson (1997)
2.2 Unsureness about practicality	Information on context-specific performance might be weak	It doesn't seem practical	Llewellyn (2007), Morgan et al. (2015), Dumbrell et al. (2016)
2.3 Complex interactions	Farmers do not know the bottom-line impact or are not sure about some unintended consequences due to a complex interaction during adoption	It wouldn't mesh well with other farming systems	Dumbrell et al. (2016)

3. Market structure and institutions			
3.1 Principal-agent or split-incentive problems	Lack of right incentive to adopt mitigation options	I'd like to try it, but my investors/suppliers wouldn't	Funk (2009),[M] Journeaux et al. (2016)[M]
3.2 Insufficient diversity of offerings	The market offers an insufficient number of variants	There isn't enough diverse choice of options	N/F
3.3 Capital market failure	Inability to finance investments	The upfront money for the investment is too hard to get out of banks	Kingi (2008),[M] Ministry of Agriculture and Forestry (MAF) (2011),[M] Daigneault et al. (2015)[M]
3.4 Supply chain failure	External factors (e.g. demands from up or down the supply chain) may preclude use of some options	I can't access the options	Botha et al. (2008)
3.5 Inappropriate or inadequate extension	Extensions may fail to meet the needs of farmers	The government seminars and information aren't clear about this	Kaine et al. (2005), Botha et al. (2008), Brown & Bewsell (2010), Sewell et al. (2014), Morgan et al. (2015)
4. Regulation and policy			
4.1 Safety or other verifications	Some regulations may require costly verification when a new option is introduced	There is a conflict with occupational health and safety requirements	N/F
4.2 Environmental regulations	An option may have environmental side effects that are restricted by the existing regulations	Maybe there are side effects modellers don't consider, which are regulated by government	N/F
4.3 Demand for new regulatory regime	New option may need some new regulatory structure before implementation	Same as above	N/F
4.4 Inadequate or inappropriate regulation	Existing regulation may be a disincentive to the adoption of a new option	The regulation does not support its use (of the option)	Kingi (2008)[M]

5. Risk and uncertainty [B]	The benefits and costs of an option may vary over different conditions	It's too risky or uncertain	Carswell et al. (2002),[M] Harmsworth (2003),[M] Abadi Ghadim et al. (2005), Kingi (2009),[M] Harmsworth et al. (2010),[M] Reid (2011),[M] Cooper & Rosin (2014), Funk (2014), Dumbrell et al. (2016)
6. Externalities	Farmers may not get (or pay) the modelled benefits (or costs)	Costs or benefits aren't just borne by me, but also by someone else	N/F
7. Behavioural factors			
7.1 First-cost bias	Farmers may put a considerably large weight on the initial cost	The first cost is too high, even though it pays off over time	Corner-Thomas et al. (2015), Rochecouste et al. (2015)
7.2 Salience bias	Potential cost savings may be overlooked by farmers	The benefits are too small to be worth the effort	N/F
7.3 Loss aversion	Farmers may put disproportionate weight on avoiding losses	I can't risk the loss, even though it's not probable	Raymond & Spoehr (2013), West et al. (2016)[M]
7.4 Inadequate managerial capability	Using a new option may require some specific skills	There is no one available who is trained to manage the farm through this	Nuthall (2006), Harmsworth et al. (2010),[M] King et al. (2010),[M] Morgan et al. (2015)
7.5 Social norms and prestige[C]	Adoption of certain no-cost options may go against social norms or prestige	It's too different from what farming has been about	Durie (1998),[M] Dewes et al. (2011),[M] Rochecouste et al. (2015), Mead 2016 [M]
7.6 Habitual behaviour	Farmers may be reluctant to change their old ways of doing things	We don't want to change our routines and habits	De Silva & Forbes (2016)
7.7 Trust or credibility	The source of information about no-cost options is untrustworthy	The source of information is not coming from someone who I know and trust, and who knows about me and my farm	Harmsworth (2003),[M] Fielding et al. (2008), Harmsworth et al. (2010),[M] Reid (2011),[M] Niles et al. (2015), Brown et al. (2016), Small et al. (2016)

[*] Evidence only from New Zealand and Australian studies. N/F (not found) indicates that no evidence was found in the literature. See Appendix 1 for a discussion on the contribution of each paper and the absence of evidence for some contexts. [M] Denotes papers studying barriers in the Māori context. [A] Includes the barriers "heterogeneity of preferences or conditions" and "variability and model incompleteness", as defined in Jaffe (2017). [B] Includes the barriers "risk aversion", "uncertainty of regulatory constraints", "the benefits and costs of an option may vary over different conditions" and "there may be fundamental uncertainty about the magnitude of the overall net benefit", as defined in Jaffe (2017). See also footnote 7 for additional considerations on this barrier. [C] Also includes the barrier "standard practice", as defined by Jaffe (2017).

3 No-Cost Mitigation Practices

Multiple farm management practices have been nominated by scientists as options to reduce biological GHG emissions (either given by methane (CH_4) and/or nitrous oxide (N_2O)) of livestock operations (Reisinger & Clark 2016; de Klein & Dynes 2017; Reisinger et al. 2018). However, if management practices increase the costs of running the farm business without changes in its revenues, their implementation will not be considered in normal circumstances. Recent work has suggested, nonetheless, that some management practices can actually maintain (if not improve) the profits of farms while reducing their carbon footprint (Smeaton et al. 2011; de Klein and Dynes 2017) – what we define as no-cost practices. In this study we focus on a subset of these practices that scientists suggest can help to achieve both lower GHG emissions and similar (or higher) levels of profits. Table 2 presents the practices we consider in this study and that are investigated in the conducted interviews. These practices come from those suggested and discussed in de Klein and Dynes (2017).

Table 2. No-cost mitigation practices, and their respective description (in non-technical language), used in the interviews.

Farming practice	Description
Dairy systems	
Reduce stocking rate (SR) and/or high breeding worth (BW) cows (increased per cow performance) – CH_4 mitigation option	A reduced SR means fewer cows per hectare, which translates into a less intensive system requiring fewer inputs and diminishing costs. The lower intensification of production reduces the carbon footprint of the farm (de Klein & Dynes 2017; Reisinger et al. 2018). Cows with a high BW are more efficient at converting dry matter (DM) into milk. This means that the same amount of milk can be produced with fewer cows and thus less dry matter produced is used to meet maintenance requirements of the cows. As CH_4 emissions are directly related to DM intake, less inputs will reduce total DM consumption and therefore total CH_4 emissions, fewer, more efficient cows can reduce CH_4 emissions per unit of milk produced. Existing modelling has shown the potential for this to reduce both GHG intensity and total emissions (Smeaton et al. 2011; van der Weerden et al. 2018).
Reduce replacement rates (fewer heifers) – CH_4 mitigation option	Improved reproductive performance of the herd results in less involuntary culling and lower replacement rates. Replacement and other non-milk-producing animals produce CH_4 and urinary nitrogen (N) without contributing to milk production (Beukes et al. 2011).

Farming practice	Description
Reduce N fertiliser use/ replace some pasture with lower N feed – N_2O mitigation option	Instead of applying N fertiliser to pasture to grow extra pasture DM, the diet is supplemented with bought-in low-N feed, e.g. the incorporation of bought-in maize or cereal silage into the diet as a replacement for N-boosted pasture to reduce the amount of excreta N returned to soil.
Sheep and beef systems	
Increase scanning percentage (better feeding/feed utilisation) – CH_4 mitigation option	The scanning percentage of ewes is driven by both the genetics of the ewe and her weight at mating. It can be very difficult in many parts of New Zealand for ewes to gain weight between weaning their lambs in summer and mating in autumn. The scanning percentage is established when an ultrasound scan is carried out on pregnant ewes. The ewes are marked as 'dry' (no foetus found), single-bearing (carrying only one lamb), or twin-bearing (carrying two lambs), or they may be scanned just for multiples – ewes carrying two, three, or four foetuses. The higher the scanning percentage, the more lambs will be born and therefore weaned. This also means that there are more lambs to be fed in spring and early summer, which can increase feed utilisation at a time when feed utilisation (feed eaten/feed grown) can be to be lower. To achieve a higher scanning percentage, ewes need to have genetic potential and be heavier when they are mated. This can be accomplished through better feeding.
Increase live-weight gain in lambs (better feeding/feed utilisation) – CH_4 mitigation option	Any ruminant animal must consume energy to grow. A lamb needs about 10MJ of metabolisable energy to grow – if a pasture is very high quality the lamb will need to eat less, but if the feed is lower quality, a higher intake will be required. However, if voluntary feed intake is limited by lower quality pasture then growth rates will be limited. Better feeding of high-quality feed will reduce total intake in lambs. Because CH_4 emissions are calculated from intake of DM, those from young stock will be reduced. However, if lambs are finished early, the impact at a systems level on GHG emissions will depend on whether farmer conserves feed, has an alternate land use (e.g. crop) or purchases more stock.

Source: Adapted from de Klein and Dynes (2017).

We explored all of these practices across the interviews but focused on only one or two per interview, in order to keep the interviews within a reasonable time frame.

For practices with reduced SR and higher BW, de Klein and Dynes (2017) argue that when both practices are in operation together, they can be considered as a no-cost option. However, in our interviews discussions and analysis we also consider the "or" case, i.e., we also looked at both practices separately. This was done because it was much easier to discuss with farmers the SR practice as a single intervention, to which we added the BW angle as we progressed in the conversations.

4 Qualitative Methodology

Semi-structured interviews were conducted with a purposive or non-probabilistic sample (Patton 2005) of a group of 14 farmers (ten dairy and four sheep and beef) across New Zealand during August 2017 and September 2018.[11] Their contact details were received from DairyNZ, AgResearch, AgFirst, and other farmers. One or two members of the research team contacted the farmers to assess their interest in participating in the study, then organised and conducted the interview. Most contacts were via email or phone, and arranged interviews were conducted in person or by phone. Interviews lasted, on average, approximately one hour.

Within the sample, four interviewed farmers were involved with farms owned by Māori groups – two dairy and two sheep and beef farms. Initial contact with these particular participants was face to face in a meeting at the farms, where one member of the research team was introduced to the farm trustees, who were asked if they would be interested in participating in the project.[12] They then consulted with other trustees who were not present at the meeting to discuss participation in the project. The research team kept contact with the trustees by email and telephone, and once the authorisation was given, carried out face-to-face interviews.[13]

4.1 Interview Design and Analysis

The interviews were based on a semi-structured discussion guide developed by the research team. A set of materials, including consent forms, a list of barriers using a non-technical definition (as shown in Table 1), and mitigation practice descriptions (described in Table 2) was also developed for the interviews.[14] The interview was divided into three parts:

1. initial questions (about all practices) to test farmers' awareness of the practices and their perceptions concerning their potential no-cost nature;
2. questions to engage a discussion of different factors and considerations related to the practical implementation of one or two practice(s), with the objective of capturing the occurrence of barriers;
3. discussion of the list of all Jaffe's (2017) barriers in order to get farmers' self-reports of the relevance that different barriers might have for the decision-making of other farmers in the region, and final questions regarding their perception of climate change.

[11] For the purpose of this research, "farmers" were people closely related to the farm management and operations, including farm operation managers, farm managers, share-milkers, etc.

[12] Māori land can be administered using several governance structures or legal entities that were designed to help Māori coordinate decision-making processes among multiple owners and reduce internal transaction costs (Kingi 2008; White 1997). The most common legal entities are Māori trusts and Māori incorporations, which centralise the decision-making process in a group of trustees or committee members, respectively. We refer to them as trustees.

[13] These interviews were carried out between August and November 2017. Audio recordings were taken and transcribed verbatim. Consent forms were obtained before the face-to-face interviews.

[14] The interview guide, including these supporting materials, is available upon request.

Most of the time spent during the interviews was used to discuss factors and considerations related to the implementation of practices (part 2). Part 1 was considered secondary in importance, while part 3 was soon reviewed.

Our analysis of most of the interview data followed a deductive qualitative content analysis process (Elo & Kyngäs 2008; Vaismoradi et al. 2013), as the main aim was to explore and identify whether or not the barriers described in the typology of Jaffe (2017) are relevant in the studied context. Using the data obtained from the interviews, we support our analyses using direct quotes from the farmers.[15]

We conducted the analysis of barriers by investigating different points discussed with farmers for a particular practice. Points discussed included, but were not limited to, the difficulties of expanding the practice, the different considerations (including practical aspects) in place to implement the practice, the internal (on-farm) and external factors of importance, and the interactions from other agents such as farm advisors or farm board members. As the main intention of the data collection was to identify the barriers for adoption of each practice, we use separate tables for each practice in the analysis (provided in Section 5.2).

5 Interview Results and Discussion

5.1 Awareness and Implementation of the Farm Practices

We started the interviews by exploring whether or not the farmer was aware of the practices listed in Table 2. We found that every interviewee knew of the practices relating to their type of farm (sheep and beef or dairy).

Even though the farmers interviewed were familiar with the use and implementation of the practices, most of them were not aware that the practices reduce on-farm GHG emissions, so they did not associate their use with an improvement in the carbon footprint of the farm. In fact, some farmers did not believe that implementing certain practices more would help to reduce on-farm emissions of GHG in an effective way. For example, as expressed in this quote:

> "Well the experts say that it [increase scanning percent] reduces greenhouse gas. Well, it's more efficient. How do you rate that? Every little helps I would say. But I mean there's no… how do you actually measure it? Which is the problem. You don't know. Nobody knows unless you put it in a chamber and measure the gases that are released into a sealed chamber. Very hard to do in a farm".

It is important to note that the practices listed in Table 2 are generally not a dichotomous choice (i.e. a yes or no case); rather, they have a range of different possible levels of use. To

[15] For ease of understanding, farmers' quotes used throughout this document are very closely written descriptions of what was verbally communicated during the interviews. All those transcriptions quoted are shown in italics throughout the document

assess the degree to which a non-dichotomous practice is applied on a farm, it is necessary to have a point of comparison. For instance, in the case of "reduce stocking rate", the number of cows operating in a farm generally changes over time and within seasons. Thus, a farmer's adoption of a particular stocking rate at a certain point in time should be compared with the farm's past records or with a benchmark farm (a similar farm in the region, for example). This implies that it is hard to evaluate whether a farm is satisfactorily applying a low stocking rate or not.[16] In our interviews, it was clearly observed that farmers knew the practices and, to some extent, were applying them, but they generally affirmed that they could have been applying them more or *"in a better way"* in their operations. Considering this, we claim that the practices were not "fully adopted" across the farms that related to our interviews.[17]

5.2 Identifying Barriers

In this section we scrutinise the data obtained in our discussion with farmers to elicit the occurrence of different barriers. Even though most of the practices discussed were understood as being currently adopted by the farmers "to some extent" (see previous sub-section and footnote 17), we attempt here to identify the barriers farmers might face in implementing these practices more (e.g. reducing their stocking rate beyond even current rates).

Tables 3–7 report on the barriers identified in parts 1 and 2 of the interviews for the five different no-cost practices listed in Table 2. We present these tables following the sequential order of the farm practices reported in Table 2, starting with the three dairy practices (Section 5.2.1) and ending with the two sheep and beef practices (Section 5.2.2). After the analysis of barriers to the five no-cost practices, we complement the analysis by presenting an identification of barriers conducted for the other two agricultural mitigation practices also discussed in some interviews (Section 5.2.3).

[16] Such an evaluation could be applied by looking at productivity measures of the farm and of similar farms in the region. However, we did not apply this analysis (see Section 6.9 for more details).

[17] It is important to note here that we did not perform any sort of analysis to estimate the optimum level of implementation of the practices across farms. This is a valid point, as farmers are often unsure about the optimal point of application of a practice, given the farm's circumstances in a particular year. Therefore, in our analysis we abstracted from productivity aspects and proceeded to identify barriers assuming that farmers could apply them more.

5.2.1 Dairy system practices and barriers

Table 3. Barriers identified to adopting the practice "reduce stocking rate (SR) and/or high breeding worth (BW) cows".

Considerations brought by farmers during discussion on no-cost practice	Farmers' main points and concerns	Identified barrier / Justification
Several factors need to be addressed extensively in low SR systems, such as more intensive grazing management to maintain appropriate pasture residuals, increased need to conserve pasture, the requirement to feed supplements in different proportion, etc. Even though the management challenges that low SR generates have been reported in the literature (e.g. de Klein & Dynes 2017; Reisinger et al. 2018), this point was brought up in all interviews where SR was discussed. The increased complexities of a lower-intensity system need to be fully considered in the modelling and analysis of SR regimes. An example of where this has already happened at farmlet scale is the P21 research programme (van der Weerden et al. 2018)	*"To be profitable with a low stocking rate you need to be a very, very good farmer."* *"You drop your cow numbers, and you grow the same amount of pasture, pasture's going to waste, that's money going down the drain. Unless you harvest it. You can harvest it, but that's a cost."*	**Modelling mismatch** / Challenges might be not properly represented in farming models or assumptions of no cost have not considered cost of increased complexity **Complex interactions** / Complexity associated with adoption means the practice may not mesh with current systems or that the complexity makes it difficult for farmers to predict bottom-line consequences. **Inadequate managerial capability** / To manage a low SR system requires skills that are not necessarily available on the farm.

Considerations brought by farmers during discussion on no-cost practice	Farmers' main points and concerns	Identified barrier / Justification
It was argued that a lower SR system may be "no-cost", but it would mean making current personnel redundant and allocating an increased workload to the remaining workers. This point is important to consider, because high profits with low SR in farms could be obtained, but could result in a reduction in staff (reducing labour inputs) and increasing the workload of remaining operators.	*"No thanks, I prefer to keep working with these people rather than to reduce my SR and my staff while increasing my personal workload."* One farmer strongly argued that he would not be willing to reduce SR even with a higher proportion of higher BW animals, because his workload and that of his operators would increase as a consequence of staff reduction in response to lower production.	**Modelling mismatch** / The unwillingness of farm managers to increase their workload after reductions in staff might be a kind of hidden cost that is not properly included in no-cost assumptions. **Risk and uncertainty** / Lack of certainty about likely consequences of adoption on staff redundancies and workload. **Loss aversion** / Avoiding loss or damage to status quo (i.e. loss of leisure time due to perception of increased workload caused by having fewer staff).
It was clearly stated by several farmers that, in order to employ a low SR system, they would need to see it consistently implemented by neighbouring farmers.	*"Farmers are always of the opinion that grasses are greener in the other side of the fence. So, if the neighbouring farms have a high SR, I may try to do the same".*	**Social norms and prestige** / a low SR would be more easily adopted if the farmer perceives in his region that is a common practice.

Considerations brought by farmers during discussion on no-cost practice	Farmers' main points and concerns	Identified barrier / Justification
A low SR system increases the importance of pasture management on the farm, which can be complex and requires more specific skills. Beyond feed management, some farmers claimed that changing a system to a lower SR requires a considerable amount of work and is, in general, a hard process that needs considerable planning. Skills are a big barrier, in general, as to manage a low SR requires that everything is managed in detail. Different skills are needed, including detailed grass management.	*"A constant surplus of grass affects your quality at the end… what about if there is no weather for silage? What the hell do you do with the surplus?"* *"Feeding is an art… not easy to change an established art."* "[To manage feed] *land could be put in grains, but it is a lot of work… a different business. Too much trouble for not much benefits."* *"To work with grass is a totally new skill."*	**Habitual behaviour** / Farmers opted not to get involved in lower SR systems because they perceive the practice involves extra preoccupations and management of pastures and other endeavours. **Unsureness about practicality** / It doesn't seem practical to the farmer as the solution appears more complex, especially in the short term. **Complex interactions** / Feed management systems are considered a complex art –The farmers perceive that it is difficult to predict what will happen to the system if SR is reduced in the short term. **Risk and uncertainty** / A low SR system brings more risk to some management, as feed management (silage and supplementary feed management, among other practices) depend on many factors that are not necessarily present with a high SR. **Salience bias** / The benefits (savings) perceived by having a low SR are not enough for farmers to engage in its implementation and the more challenging tasks involved. **Inadequate managerial capability** / To manage a low SR system requires skills that are not necessarily available on the farm.

Considerations brought by farmers during discussion on no-cost practice	Farmers' main points and concerns	Identified barrier / Justification
The decision on the SR and the BW of the animals will depend heavily on many factors. Given the complexity of the decision required, many farmers will therefore ultimately rely on the advice given by their farm advisor.	*"… at the end, the decision of a particular SR is coming from advisors".*	**Inappropriate or inadequate extension** / As stated, farm advisors have a key say in determining the SR of many farms. **Trust or credibility** / Many farmers will follow only a farm advisor's advice regarding SR. **Complex interactions** / A lot of complexity in the system means that farmers cannot predict, or are uncertain about, the consequences of changing practices and therefore abdicate the decision-making responsibility to an "expert".
Higher BW animals are more valuable per se (than the average cow in New Zealand) because they have the potential for better productive performance. Given this, some farmers think that having fewer cows with a higher BW is a missed economic opportunity. If a farm can sustain more animals per hectare (a high SR), it is a better option if higher BW animals are available, because these animals can be sold for a good price in case of need.	*"… if you were a normal farmer* [talking about a Māori farm] *and you ever chose to sell your herd, obviously you can ask a higher value for those cows if they've got a better breeding and production worth, because they obviously produce more milk, so you get more outputs out of her. You're paying more for her… but then, why to have less cows per ha (lower SR), if you can have a large capital (number of cows) in the same land?"*	**Modelling mismatch** / A low SR *and* high prevalence of higher BW cows may be seen as a lost economic opportunity, therefore a decision to adopt a low SR can be perceived by farmers as an opportunity cost. **Loss aversion** / Farmers tend to avoid loss or damage to the status quo – if the status quo is lower BW animals and a high SR, then reducing the SR reduces the value of the farmer's herd.
Regarding higher BW cows, one farmer explicitly said that they are good, but in general all animals in New Zealand are good, so there is no "necessity" to go after BW animals.	"*BW is important… but there are actually not bad cows in NZ. So, to have more higher BW animals is not a goal of our farm*."	**Variable farming landscape** / Farmers do not necessarily perceive that higher BW animals will provide a higher economic benefit to a farm that has, on average, good animals. **Salience bias** / The potential benefits of targeting BW animals are considered too small for the effort.

Considerations brought by farmers during discussion on no-cost practice	Farmers' main points and concerns	Identified barrier / Justification
Seasonal variability is clearly a concern raised in connection with low SR systems.	*"The thing is, if you can have less cows and still produce the same amount of milk solids… Sure, everyone will do it! Because that means the farm becomes more self-sufficient.* [But] *because season to season is different, you know, you can't just say you're having a good season, because next year it could be a bad season."*	**Risk and uncertainty** / Low SR systems are perceived as riskier than systems with a higher SR.
A couple of farmers claimed that dry seasons make it very difficult to have many cows, so the observed SR may not necessarily resemble what the farmer would actually do in good conditions.	*"Another thing is the weather… the drier, the harder."*	**Risk and uncertainty** / In a dry season, farmers will be more risk averse and just cull multiple cows, but in a good season they become risk lovers and tend to have as many cows as possible. **Loss aversion** / According to their perception, if farmers do not have more animals in good times, they might be losing money.
The decision to structurally reduce the SR affects the business model of the farm. This decision might not necessarily be impeded because of capital constraints or willingness to implement it, but rather because of lack of adequate communication and/or coordination with owners to implement the practice.	*"… it's not a lack of capital* [to reduce SR]*; it's an abundance of opinions. There is a board behind this."* *"I prefer to avoid a discussion with the board and continue operating as is."*	**Complex interactions** / Given that multiple social interactions may be required for decision-making, the important decision to reduce SR is sometimes impeded by the complexity of the governance that is in place. **Principal-agent or split-incentive problems** / Farm operators can receive mixed messages or incentives from investors or governance boards. **First-cost bias** / Farm operators might prefer to avoid short-term conflict and/or negotiations with the farm's board if the benefits are not clear in the medium term.

Considerations brought by farmers during discussion on no-cost practice	**Farmers' main points and concerns**	**Identified barrier / Justification**
Even though herd testing is considered standard practice, we observed variability in the number of herd tests performed across farms, with one farmer even suggesting that no herd tests had been applied to his herd in a recent year. Herd testing is needed to provide data on productivity across cows, so that better decisions can be made if a reduced SR is sought. Thus, any decision made regarding the knock-out (culling) of cows requires information. Herd tests are a good source of information, but if farmers face any financial challenge, there is a chance that they are not prepared to pay for herd testing.	*"Well, I can't say* [when asked about the potential to reduce SR]*, because I've not done a herd test. See, last year we didn't do any herd tests because the dairy price went down, so we slashed all our costs."* *"Yeah, I could knock 20 cows out of the herd now, but I'm waiting for my first herd test on the 12th of this month… You know, you can't just knock a cow out. You know I've got responsibilities to the trust so I've got to have a reason why I'm culling her."*	**Inadequate managerial capability** / Herd testing is one tool to lend confidence to decision making on reducing SR. In general, it is assumed that farmers would perform regular herd tests, but the reality is that decisions relating to this vary considerably according farmers' management. **Capital market failure** / Even though investments required for a herd test are not large, financial constraints show to be an issue here, which can constraint SR decisions.
An important point raised was that to manage a farm properly, either by reducing the SR or by expanding the use of other practices such as reducing replacement rates, the farm operations manager should be very familiar with the different characteristics of the farm, but this is difficult to achieve because farm managers frequently move between farms. According to two interviews, it is rare to find someone working in the same farm for more than four years, which makes "paddock knowledge" hard to obtain.	*"To manage properly a low SR system, combined with high BW cows or not, you need to know extremely well all the paddocks of your farm."*	**Learning and adjustment** / The reallocation of farmers (labour) within and across the industry (moving from one dairy farm to another or from a dairy farm to a sheep and beef farm, for instance) has not been properly considered in farm-level models, thereby missing the costs that learning (and intuitive decision making) can bring. **Variable farming landscape** / This learning and adjustment can be noticeably important because of the heterogeneity and variability between different farms.

Considerations brought by farmers during discussion on no-cost practice	**Farmers' main points and concerns**	**Identified barrier / Justification**
BW animals, as stated by some farmers, are not the best option in some regions.	*"We have plenty of grass here and use Friesian cows, so we do not need to target BW at all."*	**Unsureness about practicality** / Lack of knowledge on relative potential of current vs high BW cows can curtail their adoption. **Variable farming landscape** / High BW animals can have potential for reducing footprint in lower input farm systems; however, the value is highly dependent on the management of the system.

Table 4. Barriers identified to adopting the practice "reduce replacement rates".

Considerations brought by farmers during discussion on no-cost practice	**Farmers' main points and concerns**	**Identified barrier** / Justification
Farmers stated that they actually seek to have a reduced replacement rate on their farms, but that it involves complexities. Expanding this practice requires a "*very high in-calf rate*", which is hard to achieve.	*"This is definitely something that we target, but is very difficult to achieve… There is just too many details to follow during mating… it is hard."* [to expand this practice]*"… means to have someone looking at the animals all the time, which is time-consuming."* *"You need to have good work done all the time. Attention to details during mating!*"	**Inadequate managerial capability** / Too many considerations are needed, which are beyond the available skills/capacity on the farm. **Complex interactions** / Too much complexity in the system means that it is very difficult for farmers to predict the consequences of their actions. To have high in-calf rates which is required for low replacement rates is very difficult to achieve.

Considerations brought by farmers during discussion on no-cost practice	Farmers' main points and concerns	**Identified barrier** / Justification
Farmers associated this practice with a high level of risk.	*"It is simply too risky… we need to have a good number of animals in case we have any issues with diseases or similar."* *"Many unpredicted things happen in this business, so to have cows waiting in the run-off would always be necessary."* *"The other risk are diseases that could come with cows that you buy from outside."*	**Risk and uncertainty** / Risk is a clear barrier for a further (more intensive) implementation of this practice.
Interviewees pointed out that the practice is not easily accepted by farmers because, if it is implemented more, they will need to get animals from other farms – something not many farmers like to do.	*"If you don't have the cow to replace a cow that dies unexpectedly, you need to buy the replacement from another farm, and people do not want to do that."* *"People want to be self-contained. They do not want to buy other animals from another farm."*	**Unsureness about practicality** / Farmers will not be keen to expand the use of the practice because it is not practical for them the process of buying animals in other farms. **Habitual behaviour** / Farmers want to continue with their current practices and feel uncomfortable about changing their routine of how to replace animals.
A farmer stated that reducing replacement rates brings with it the challenge of limiting the potential genetic improvements that you can bring to your herd.	*"If you don't keep bringing younger cows to your herd, you can miss out on genetic opportunities to improve production."*	**Modelling mismatch** / This is an opportunity cost that could limit the adoption of this practice.

Table 5. Barriers identified to adopting the practice "reduce N fertiliser use/replace some pasture with lower N feed".

Considerations brought by farmers during discussion on no-cost practice	**Farmers' main points and concerns**	**Identified barrier** / Justification
To implement this practice in a correct way requires many steps over many years, creating a long process that is difficult to bear in a commercial dairy farm.	*"Changing the fertiliser regime is a longer-term investment, and it might be 10 years before you start to get the full benefit of that."*	**Salience bias** / The practice was identified as providing savings in a time frame that is not operational for farm managers.

5.2.2 Sheep and beef system practices and barriers

Table 6. Barriers identified to adopting the practice "increase scanning percentage".

Considerations brought by farmers during discussion on no-cost practice	**Farmers' main points and concerns**	**Identified barrier** / Justification
Scanning can depend on the size of the farm and the number of animals. If the area of the farm is small and the farmer has few animals, he or she may not be interested in scanning and separating the animals.	"[After being asked if the practice was something to implement always] *No, just because in a management system, if I haven't got many sheep and I scan my sheep, then instead of having one mob of sheep, now I've got to have two mobs of sheep, so maybe my twins and my singles, and possibly my triplets, and if I've only got a small farm and not many sheep, then it might not be worth splitting them into different mobs. So I might not bother to scan."*	**Unsureness about practicality** / Increasing the scanning rate might work, but it might not be practical to implement it all the time, especially with a low number of animals. **Salience bias** / the benefits of scanning on smaller farms is not considered worth the effort required.
Some farmers stated that this practice might not be broadly implemented by farmers because it goes beyond what they normally do on their farms.	*"I think for me, when I look at scanning and growing animals faster, I can't see why people wouldn't do it, so it probably comes down to the fact that they just can't be bothered. Probably comes back to the fact that it's just not what we do, and we don't have the energy to do it, I suppose."*	**Habitual behaviour** / Farmers seem to be unwilling to expand this practice as it requires more effort and time.

Table 7. Barriers identified to adopting the practice "increase live-weight gain in lambs".

Considerations brought by farmers during discussion on no-cost practice	**Farmers' main points and concerns**	**Identified barrier** / Justification
Better feeding is associated with high-quality pasture that requires upfront investment and can result in high costs to farmers. Farmers may need to deal with a new crop and the animal performance to maximise their growth.	"[After being asked about costs associated with this practice, including, but not limited to, financial costs] *whenever we invest some money up front, we've kind of got our fingers crossed that a whole lot of things go right to get that investment back again, so there's a little bit of risk there.*" "[After being asked about risks or uncertainty associated with special pasture] *So that's probably the biggest one for me in my decision-making… is the risk of a crop failure. So you spend a lot of money up front, and you might not get the yield that you expected. There's a risk that animals won't do quite as well as you planned on the crop. There's also a risk that it might not be worth as much at the other end.*" "*We're spending money up front and then every time we spend money up front we've got to recuperate it and make some more as well… The risks are largely financial.*" "*… sometimes cash flow's tight, so guys would love to do it, but they just haven't got the cash flow at that time of year to be cropping*".	**Risk and uncertainty** / The quality of the crop and its profits are susceptible to exogenous factors, such as the location of the farm, weather conditions, or financial constraints, which generate risk and uncertainty. **Complex interactions** / The practice involves complex interactions, with lots of room for uncertainty and for something unexpected to happen. **First-cost bias** / The upfront costs, along with the uncertainty of outcomes, present a barrier to this practice change.

Considerations brought by farmers during discussion on no-cost practice	Farmers' main points and concerns	**Identified barrier** / Justification
This practice requires a learning process about a new farm management practice, which can represent extra cost.	"*Sometimes if we complicate systems, we notice with our guys that there's a cost sometimes when guys are learning new crops and different ways of doing things*."	**Habitual behaviour** / Farmers seem to be unwilling to expand the use of this practice as it requires more effort and time. **Learning and adjustment /** The process behind learning how to manage a new crop can be perceived as expensive and can limit the adoption of new crops.
Even though it was stated by a couple of farmers that "*If you know what you want, you can go and find it*", some forages are new to New Zealand. This implies not just a restricted access, but in many cases costs to produce trials and test how effective they are in different situations.	"[In order to get even more live-weight gains] *we need to start using new forage, and some of them are new to New Zealand, so we need to test them, we need to do some trial work.*"	**Modelling mismatch** / To increase the rate of adoption of this practice, some farmers need to innovate with new forages and feed. However, this can bring initial costs of trials and tests across seasons that may not be considered in models. **Insufficient diversity of offerings** / Some new forages that have the potential to improve this practice are still very recent arrivals in New Zealand, so are not readily available to farmers. **Risk and uncertainty** / With new forages come new risks and new unknowns, leading to unsureness about practicality (see below). **Unsureness about practicality** / This arises in situations where the context-specific performance information about the practice (the use of a new crop) is weak.

Considerations brought by farmers during discussion on no-cost practice	Farmers' main points and concerns	**Identified barrier** / Justification
On different occasions the farm owner or board might not realise that some skills are not available in the farm.	"*We decided we are going to start using a new forage and there were a lot information about it, but the management of this forage is different to the one we had… the manager we had was doing reasonably well, but the forage was not growing well. After several years, just when we were about to stop having this new forage, the manager left and the new manager we got had more experience with this new forage… without a dramatic change in management, but changing a couple of those key things, he improved the yield of the forage dramatically, so instead of stopping producing it we increased it to double to what we had!*"	**Inadequate managerial capability** / Some farm owners might not realise that their managers do not have the skills to operate a particular option in an efficient/optimal way. **Unsureness about practicality** / Farmers might have a wrong believe that a practice is not efficient, when in reality it can be very practical and useful.

Table 8. Barriers identified to adopting the practices "use of bobby calves", and "once-a-day (OAD) milking".

Considerations brought by farmers during discussion on practice	**Farmers' main points and concerns**	**Identified barrier** / Justification
On using bobby calves The use of this option is something that involves not just the beef industry, but also the dairy sector.	*"This does not depend only on the beef farmer, but we need more beef genetics in the dairy industry, which is a change for the dairy farmer, it is a bit of a change in their thinking, so there is a limitation there. And it is also a change for the beef farmer."*	**Complex interactions** and **supply chain market failure** / This is a combination of these two barriers. Systems interaction is a barrier because you need coordination between different industries, and capital market failure is a barrier because there is no clear mechanism to align these different interests. **Habitual behaviour** / This includes the need for change from both dairy and sheep and beef farmers (and sectors) and the need to overcome conflicts with traditional behaviour and practice.
On OAD milking Initial costs and drop of production are key barriers to the adoption of OAD milking.	"[To implement OAD milking] *you lose production a lot at the start".* *"The first year is just horrible."* "*People with high debt do not want to risk going once a day. It is a huge risk for people to take."*	**First-cost bias** / The initial costs of switching to OAD are so large that they deter farmers from even considering this option. **Risk and uncertainty** / Production drops so considerably in the first year of an OAD system that risk increases.

Considerations brought by farmers during discussion on practice	Farmers' main points and concerns	**Identified barrier** / Justification
On OAD milking Even though it has been affirmed that levels of production and profits can be recovered after a couple of years of operation of OAD, farmers simply do not believe it.	*"They reckon within 3 years you will get to the same level that you were on twice a day milking… I mean it is hard to believe… I will love to see it myself. I have never seen it in the full season."* *"It is quite new what people are doing… and people are not really believing… I heard of it but I do not believe it myself."*	**Trust or credibility** / Farmers are very reluctant to believe that OAD can achieve good results, which is clearly limiting the adoption of the practice. **Unsureness about practicality** / Farmers do not believe that OAD is a practical system with high production returns. **Habitual behaviour** / A reluctance to change current practices is due to doubt about practicality and/or lack of trust in an information source regarding OAD.
On OAD milking OAD seems good on paper, but farmers strongly believe that twice-a-day milking will always outperform it.	*"Yes, people say that after 3–4 years they can recover volume to what they have with twice a day, but what they miss is that with twice a day you keep also improving your numbers, so you will never know how much you are missing."*	**Unsureness about practicality** / Farmers do not believe that OAD could ever surpass twice-a-day milking. **Trust or credibility** / Some farmers do not find credible that OAD would ever be better than twice a day.

5.2.3 Barriers identified as affecting the adoption of other practices

Although the main intention of the interviews was to identify barriers related to the five "no-cost" practices listed in Table 2, in some cases they diverged and discussed other management practices that have also been linked to GHG mitigation. In particular, these practices included once-a-day (OAD) milking (Reisinger et al. 2018), and using bobby calves discarded by dairy farms in beef operations (Reisinger & Clark 2016). From the discussion of these practices, some barriers were also identified; these are presented in Table 8.

5.3 Farmers' Opinions on the Full List of Potential Barriers

Once we completed the discussion with farmers about different considerations of the selected practices, we proceeded to discuss with them what they thought about the list of barriers proposed in Jaffe's (2017) typology. To do this, we presented the farmers with the list of barriers, accompanied by their non-technical definitions (as described in Table 1), and asked them to comment on the ones they found relevant. The main aim of this part of the interview was to give the participants an opportunity to highlight which of the barriers they thought were more important for farmers. As we provided the list of barriers, this analysis did not seek to identify the occurrence of barriers in particular contexts, but rather to get a general idea of the relative importance of the barriers according to the knowledge of the farmers.

Table 9 lists selected quotes for all barriers that received comments from farmers. In some cases, more than one quote is presented to illustrate the diversity of comments received for the respective barrier. The barriers with no quotes are cases where we received no feedback from the farmers with regard to that specific barrier.[18]

Table 9. Farmers' direct impressions on barriers.

Barrier	Non-technical definition (as in Table 1)	Points raised by farmers (quotes)
1. Arguably efficient		
1.1 Modelling mismatch	The practice does have costs!	
1.2 Option value	I'll try it one day, but not yet	
1.3 Variable farming landscape	The model doesn't reflect the landscape of my farm	*"This is definitely true given pasture yields."* *"Their excuse is: that will work there, but it won't work for me."*
1.4 Learning and adjustment	It pays off only once we have learnt how to do it, but the learning process is too expensive	*"Farmers don't want to be the guinea pig and try the new practices or technologies. They prefer to wait if the novel option works on another farm and, depending on the results, they would decide to replicate or not."*

[18] We did not ask farmers to provide opinions on *all* barriers, only the ones they found relevant.

Barrier	Non-technical definition (as in Table 1)	Points raised by farmers (quotes)
2. Information		
2.1 Awareness	We just didn't know	*"Awareness is not an issue!"* *"Farmers are knowledgeable fellas."*
2.2 Unsureness about practicality	It doesn't seem practical	*"Some farmers can be located in an isolated place. So have no access to see the practice implemented elsewhere."* *"Farmers are people that like to be able to see it. They like to go see someone else doing it first: to go over and have a look, see them doing it, and have a think about it, then do it."*
2.3 Complex interactions	It wouldn't mesh well with other farming systems	*"... very often something looks quite good in isolation, but then when you try to fit it in with everything else it gets quite difficult. This is quite a big barrier."*
3. Market structure and institutions		
3.1 Principal-agent or split-incentive problems	I'd like to try it, but my investors/suppliers wouldn't	*"Definitely an issue with share-milkers."* *"The board also rules here."*
3.2 Insufficient diversity of offerings	The choice of options isn't diverse enough	*"If you want to get information on organic agriculture in the country, you need to really in foreign sources. There is simply no reliable source of organic practices in New Zealand."*
3.3 Capital market failure	The upfront money for the investment is too hard to get out of banks	*"Banks will definitely support conventional operations. Food Inc. paradigm!!"* *"Most farmers have high debt, so they can't afford to change."*
3.4 Supply chain failure	I can't access the options	*"Access is key, they are there, but they are not necessarily available at hand. Especially in the long-term game... to plan a lower SR could be restricted by low access to options, especially financial options."*
3.5 Inappropriate or inadequate extension	The government seminars and information aren't clear about this	*"Nobody talks about this still from the GHG perspective"* *"I have participated in many talks given by industry, and so far have not heard about on-farm GHG."*
4. Regulation and policy		
4.1 Safety or other verifications	There is a conflict with occupational health and safety requirements	
4.2 Environmental regulations	Maybe there are side effects modellers don't consider, which are regulated by government	*"Our focus now is on N leaching and water. To be honest, to control GHG is not in our interest."*
4.3 Demand for new regulatory regime	Same as above	*"Look, at the moment, if you are a farmer who doesn't really care that much, being a little harsh on the environment is not a real cost... you can argue, where is the motivation?"*

Barrier	Non-technical definition (as in Table 1)	Points raised by farmers (quotes)
4.4 Inadequate or inappropriate regulation	The regulation does not support its use (of the option)	*"Farmers can be reluctant to the change, even if they are doing some minor changes, their adoption might require external nudge, for example a law."*
5. Risk and uncertainty	It's too risky or uncertain	*"Risk is key. Farming is a risky activity already, so farmers will try to avoid extra risk as possible."*
6. Externalities	Costs or benefits aren't just borne by me, but also by someone else	
7. Behavioural factors		
7.1 First-cost bias	The first cost is too high, even though it pays off over time	*"This is always an issue!"*
7.2 Salience bias	The benefits are too small to be worth the effort	
7.3 Loss aversion	I can't risk the loss, even though it's not probable	*"There is a sentiment that if you produce less milk you are going to make less money."*
7.4 Inadequate managerial capability	There is no one available who is trained to manage the farm through this	*"When you are working with systems that you don't have experience with, it can be quite a hurdle."*
7.5 Social norms and prestige	It's too different from what farming has been about	
7.6 Habitual behaviour	We don't want to change our routines and habits	*"The fact that they have been doing things in a certain way creates some resistance to change. The traditional way of doing things is a habit that takes a long time to be changed."*
7.7 Trust or credibility	The source of information is not coming from someone who I know and trust, and who knows about me and my farm	*"There is a lack of trust in the source of the information of possible practices and also the environmental impact of their practices."* *"It is much easier to change behaviours if they can see the damage. It happens with water quality or erosion, but regarding greenhouse gas emissions, it is hard to see the outcome of GHG emissions."*

Note: Blank cells reflect no feedback received by farmers for the respective barrier.

6 Discussion of Results

In the following, we summarise and discuss main findings separately in different sub-sections, based on the topic being analysed. We also finish this section with a sub-section devoted to discuss our research caveats.

6.1 Non-mitigation evidence from the literature review

Many papers do highlight the importance of barriers to the adoption of different practices and options in agriculture. From the reviewed literature, we found that the barrier "inappropriate or inadequate extension" has been widely identified in past research. This barrier suggests that external extension agents in New Zealand do not necessarily have incentives to promote environmentally friendly practices with farmers, which will undoubtedly also affect the uptake of potential mitigation options. Other important barriers for New Zealand (given the relatively high number of papers found) are "variable farming landscape", "learning and adjustment", "awareness", "risk and uncertainty", and "inadequate managerial capability".

In contrast, we found no evidence in the New Zealand and Australian literature for several barriers that on paper seem relevant for farming contexts (these are indicated by the "N/F" cells in Table 1). This lack of evidence does not necessarily mean that these barriers are not important in New Zealand (or Australia), but these could be outside the scope of the reviewed papers – to the best of our knowledge, no study focused on exploring the occurrence of multiple barriers as described in Jaffe (2017). This gap in knowledge is precisely what we attempted to fill through the interviews conducted as part of this research, although our focus was mostly on identifying barriers related to no-cost mitigation practices.

6.2 First finding from interviews: awareness of no-cost practices

The no-cost mitigation practices that were the focus of the interviews (see Table 2) were widely known by farmers. However, most farmers had no knowledge that the practices support a lower farm carbon footprint. This indicates a general lack of awareness of GHG mitigation practices or options and most likely a corresponding lack of awareness of the importance of reducing on-farm GHG emissions –what we define as a lack of "mitigation awareness". In some cases where farmers knew that the practices have been linked to lower GHG emissions, or after we (the researchers) had told them this, this claim was treated with scepticism. This last point relates directly to the barriers, "unsureness about practicality" and "trust or credibility".

6.3 Frequency of identified barriers across no-cost practices

As seen in Table 10, across the five no-cost practices we identified the occurrence of 16 different barriers. "Arguably efficient", "Information" and "behavioural factors" are the three categories of barriers most frequently identified from the interviews.

Table 10. Frequency of identified barriers across no-cost practices

Barrier	Frequency of barrier identified in practice					
	SR/BW	RR	N fert.	Scanning	Weight	*Total*
1. Arguably efficient	**8**	**1**	**-**	1	2	*12*
1.1 Modelling mismatch	3	1			1	*5*
1.2 Option value						
1.3 Variable farming landscape	4			1		*5*
1.4 Learning and adjustment	1				1	*2*
2. Information	**7**	**2**	**-**	1	3	*13*
2.1 Awareness						
2.2 Unsureness about practicality	3	1		1	2	*7*
2.3 Complex interactions	4	1			1	*6*
3. Market structure and institutions	**3**	**-**	**-**	-	2	*5*
3.1 Principal-agent or split-incentive problems	1					*1*
3.2 Insufficient diversity of offerings					1	*1*
3.3 Capital market failure	1				1	*2*
3.4 Supply chain failure						
3.5 Inappropriate or inadequate extension	1					*1*
4. Regulation and policy	**-**	**-**	**-**	-	-	
4.1 Safety or other verifications						
4.2 Environmental regulations						
4.3 Demand for new regulatory regime						
4.4 Inadequate or inappropriate regulation						
5. Risk and uncertainty	4	1	-	-	2	*7*
6. Externalities	-	-	-	-	-	
7. Behavioural factors	**12**	**2**	**1**	2	3	*20*
7.1 First-cost bias	1				1	*2*
7.2 Salience bias	2		1	1		*4*
7.3 Loss aversion	3					*3*
7.4 Inadequate managerial capability	3	1			1	*5*
7.5 Social norms and prestige	1					*1*
7.6 Habitual behaviour	1	1		1	1	*4*
7.7 Trust or credibility	1					*1*
Total	***34***	***6***	***1***	***4***	***12***	*57*

Note: SR/BW: Reduced stocking rate and/or high breeding worth cows; RR: Reduced replacement rates; N fert: Reduced N fertiliser use/replacing some pasture with lower N feed; Scanning: Increased scanning percentage; Weight: Increased live-weight gain in lambs. Blank cell means the barrier was not identified.

The practice most discussed with farmers (dairy farmers, in particular) was the reduction of the stocking rate (SR). This practice received more attention in the interviews discussions because of two following reasons. First, it represents a managerial task that farmers deal with all the time – to decide how many cows to work with – which raised their interest in the debate. Second, its further adoption (to reduce SR across current numbers on the farm in the short and medium terms) generally involves challenging managerial tasks and considerations, so several implications were considered.

In part, as result of the longer conversations about reducing the SR, but also because of the different complexities and implications associated with its implementation, this practice received the largest number of identified barriers in this study. It is important to point out here that de Klein and Dynes (2017) summarise past scientific evidence claiming that SR can be defined as a "no-cost" option only when it is applied concurrently with a targeting of high breeding worth (BW) cows. However, based on the discussions in the interviews, more barriers were associated with the decision to reduce the SR of a farm than the decision of how many high BW animals to have. In total, 35 barriers were identified across different considerations of this practice (see SR/BW total in Table 11), of which only eight related to the adoption of high BW animals.

In the SR/BW practice we identified 15 different barriers, which is for far the largest number across practices. This finding in particular points that this practice is embedded with multiple factors that affect the decision-making of farmers from different angles, precluding the further use of this practice. On the other hand, the practice "Reduced N fertiliser use/replacing some pasture with lower N feed" received the lowest number of barriers in our analysis (only one), suggesting that the implementation of this no-cost practice could be less constrained by non-financial barriers than the rest.

Any of the barriers in the category "regulation and policy" were identified in our analysis of the no-cost practices, but it was mentioned that regulation would require or compel changes in farmers behaviours. See for instance this quote of a farmer when asked for any final comments at the end of the interview:

> "Yeah, I think for me, probably I think we need more regulation. For right or wrong, I think it is essential to change a lot quicker than letting farmers change on their own accord. I guess I just don't think New Zealand farming, at the moment, we're not doing enough to change on our own.

Finally, and in line with our findings from the literature review, we uncovered no evidence on the occurrence of several of the barriers listed in the typology of Jaffe (2017) – resembled by the blank rows in Table 11. Of course, the fact that these barriers were not mentioned by the interviewees it is not evidence of absence. However, it does appear that these barriers are not especially prevalent in New Zealand – yet.

6.4 A focus on the "arguably efficient" barriers

The category "arguably efficient" points that failures in the calculation of the cost and benefits of certain practice can affect farm's profitability and therefore the adoption of this practice (Jaffe 2017). The three barriers mentioned during the interviews that can be considered as financial barriers to adoption are: "modelling mismatch" (the case when the practice does have higher operational costs than benefits), "variable farming landscape" (the previous case, but just in the context of certain farms) and "learning and adjustment" (when the learning process is too expensive). Of these three, the most important in our analysis was modelling mismatch, which was identified six times – four of them in the practice "low stocking rate and/or high breeding worth animals" (SR/BW) and one in "reduced replacement rate" and "Increased live-weight gain in lambs". This result shows that, for at least some farmers, these practices (in special SR/BW) are perceived to have a financial cost that outweigh benefits, which constrains their further adoption. One implication of this is that farmers expect more evidence of the profitability-enhancement potential of some no-cost practices in different scenarios, so as to be more aware of their costs in different specific contexts. Thus, on many occasions farmers stated that there was a misleading message from policy/technical discussions that mitigation practices will work across most farms, which they emphasise is not necessarily the case. This was relevant across different contexts, where farmers claim that some costs and farm complexities are not properly considered when the practice is defined as no cost. Farmers claimed that more effort should be put in to clarify the costs of the practices (especially in the form of the farmers' time) in specific contexts, varying timescales, and their opportunity costs with respect to their currently used practices.

The considerations of these findings are relevant because no-cost practices are many times identified by engineering–economic analyses that quantify the costs and benefits of different options using a combination of data, models, and other tools. But these types of analyses consider only a finite number of aspects and frequently miss the heterogeneous complexities of farming contexts (Jaffe, 2017). This seems to explain why the barriers "modelling mismatch" and "variable farming landscape" are particularly relevant in our findings: in part, some practices deemed no cost are not being more adopted as a consequence of the costs involved with their further application, costs farmers claim are not offset by benefits.

6.5 Pure non-financial barriers

Our analysis suggests that barriers are linked to one another. Implementing no-cost mitigation practices involves manipulating variables within the farm system. For instance, "Complex interactions" through lack of predictability can create "risk and uncertainty", leading to "unsureness about practicality" of a practice. This interconnection explains in part why these three barriers were among the most identified ones in our analysis.

Other barriers frequently identified were "risk and uncertainty" and "inadequate managerial capability" (the lack of skills in the farm to comprehensively manage the practice). The former was identified seven times across three different practices, while the latter was identified five times in three practices (as shown in Table 11). Although each barrier is part of a different barriers' categories from Jaffe’s (2017), these two barriers were referred by farmers as a justification for no further use the practices, as a result of increasing risks and difficulty of the application, skills-necessity and managerial stress.

As highlighted in other studies looking at the adoption of farm practices (e.g. Small et al., 2016), we found that farmers can be very reluctant to change and in general trust only in the judgement of farm advisors – “trust or credibility” barrier. Doing things in a traditional way is a habit, and the adoption of a no-cost practice might therefore require trustworthy and credible information or an external nudge (e.g. a policy). It is more likely that farmers will decide to adopt or experiment with a new practice if the information comes from a source that is credible to them, a way to overcome the barriers of “trust or credibility”.

It was also commonly stated in the interviews that farmers would want to see practical demonstrations of the new practices working successfully on a property similar to theirs before they make changes in their own farming system –a similar point is reached in Small et al. (2016). Thus, if the aim is to encourage their adoption by farmers, it is therefore important to establish examples of successful GHG reduction, using the mitigation practices described, in a range of different farming landscapes. This could help to overcome the barrier “unsureness about practicality”.

6.6 Points on barriers identified with other practices

Even though the practices that were the focus of this study cannot be considered no cost, our discussion with farmers allowed us to identify several barriers that are worth mentioning. On many occasions, the barriers “risk and uncertainty” and “unsureness about practicality” were raised during the discussion with farmers. Many interviewees stated that the practices (especially “once-a-day milking”) could be risky as there is loss of production in initial years, and that they do not believe the farm will perform better under the practice.

An interesting point raised with regards to the use of bobby calves relates to the need to better integrate the dairy and sheep and beef industries. This point, which we identify as “complex interactions” and “supply chain market failure” barriers, goes beyond the willingness of the farmer, but points to a space where industry could try to improve the alignment of interests and mitigation efforts between parties.

6.7 Perceptions of climate change as a barrier?

One important consideration not discussed above, which directly affects the adoption of mitigation options, is farmers’ perceptions of climate change. Providing an international perspective on this topic, Prokopy et al. (2015) compares farmers surveys in six locations (Scotland, Iowa (USA), California (USA), Australia, and two regions in New Zealand) to understand their beliefs as they relate to climate change causation and the perceived risks involved with climate change, as well as their support for adaptations and/or mitigation initiatives. The authors conclude that farmers' beliefs about climate change can be influenced by climate change impacts and polices. In Australia, where impacts have been the highest of the four countries studied (as claimed by the authors), farmers are more likely to believe in the anthropogenic cause of climate change. In contrast, Prokopy et al. (2015) claims that New Zealand farmers are more concerned about climate change policies than biophysical climate change risks. In our interview sample, the majority of farmers believed that climate change is happening, but that agriculture is just a minor source of the problem. In general, they seemed inclined to improve practice to reduce emissions, but awareness on mitigation practices was still limited.

This is important because, in general, a different barrier to farmers' adoption of GHG mitigation practices is a lack of belief in anthropocentric climate change, or (if climate change is acknowledged) a lack of belief that agriculture is responsible for significant GHG contributions, or a lack of belief that farmers' practices can effectively reduce GHG production. When such beliefs are held, it would appear futile to consider GHG mitigation practices.

Getting farmers interested in learning about GHG emissions and possible mitigation practices or options can be challenging. More than once, interviewees made comments such as:

> "it would much easier to change behaviours if they could see the damage, or at least could see other farmers caring and applying a practice to prevent the damage [or emission]. It has happened with water quality or erosion, but it is hard to identify direct outcomes from GHG emissions in the farm."

There are considerations regarding the nature or existence of the problem, as well as the efficacy of actions to bring about the proposed outcome. When cause and effect are separated in time and space (as in the case of GHG emissions v impacts), farmers have difficulty believing that they are related or that a new action may change the effect:

> "Well, I think if you can tie efficient use of pasture to reduction in greenhouse gases, then yes. But you've got to actually tie them up. So okay, if you do this, you will get better-quality feed and your animals will use it more efficiently, and your result will be lower greenhouse gas emissions per unit of product. Not necessarily per animal, but per unit of product."

Even if it is proved scientifically that no-cost practices can efficiently reduce GHG emission on farms, false beliefs about the inefficacy of the practices could be a major barrier to their uptake by farmers. This again illustrates the need for information to be delivered to farmers by people whom they trust – in general, farm advisors or other respected farmers who are currently successfully applying the practice in question. Farmers need to better know the "why, what and how" of agricultural mitigation.

6.8 Research Caveats

Even though the data obtained from the interviews do provide interesting points and give a better understanding of the occurrence of different barriers, our research approach has some limitations that should be taken into account when interpreting our conclusions.

First, our sample of farmers was small, so we could have missed important barriers and implications affecting other farms across different regions of the country. Although this point is valid for most qualitative studies based on interviews, it is important to take it into consideration for this study. In other words, the set of barriers we identified in this study should not be taken as the only ones happening in New Zealand farming. Nevertheless, this caveat does not affect the relevance of our findings, as we do identify and discuss barriers that are affecting decision-making by farmers in the country. The barriers we identify here can be targeted by national and industrial policy in the future in order to promote the increased adoption, or expansion, of GHG-friendly practices.[19]

Second, before the interviews were held we had no information about the specific management practices and environmental performance of the interviewees' farms. Given this, we could not target specific questions regarding the performance of the farms in terms of environmental and management practices. More closely targeted questions could have provided better information regarding the efficiency of practices for GHG reduction and profit. In addition, we did not perform any sort of productivity analysis to estimate the optimum level of implementation of the no-cost practices across farms. In general, farmers are unsure about the optimal point of application of a practice, given the complexities of farms and circumstances in a particular year. Therefore, we had neither prior nor interview-revealed information about the optimal level of application of a no-cost practice on the farms. In most cases, however, farmers implied that no-cost practices could have been applied more or *"in a better way"* in their operations.

Third, we interviewed farm managers from four Māori farms that have had exposure to other projects associated with mitigation options. Although we did not aim to compare their outcomes with non-Māori farms, we did not identify any clear differences in the decision-making process regarding farm management practices.

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[19] This caveat also applies to our small sample of Māori farms.

7 Conclusion

Complementing the large recent investments that the New Zealand government has made to fund programmes and research aimed at evaluating whether and to what extent different farming practices can support the mitigation of on-farm greenhouse gas (GHG) emissions, this study shed lights on the adoption part of these. This study focuses on win–win practices (those capable of reducing GHG emissions and at the same time sustaining economic viable pastoral systems, what we define as "no-cost" practices) and the barriers that can explain the low use or adoption of these practices. In particular, we identify in this study, the presence of barriers to farmers' decision-making when evaluating five no-cost practices and two alternative mitigation practices.

Our identification of non-financial barriers is theoretically grounded in the typology of barriers to adoption developed by Jaffe (2017), then empirically analysed with a literature review of agricultural adoption, and illustrated by interviews with 14 farmers across the country. In particular, the interview analysis is the main contribution of this study, as we focused on farmers' understandings of different practices and their perceptions regarding the implementation of the practices, and on what factors they face that constrain their decision to implement. We found evidence suggesting that different types of financial and non-financial barriers affect the rate of use or extent of application of no-cost practices.

An initial conclusion, with respect to the studied no-cost practices (listed and described in Table 2), is that while all interviewed farmers were familiar with them, a vast majority were not aware that the practices could contribute to reducing on-farm emissions. In other words, awareness was not a barrier from the productive point of view, but it was from an environmental management angle – a lack of "mitigation awareness".

We identified the occurrence of 17 different barriers across the interviewed farmers, of which three can be considered as financial barriers: "modelling mismatch" (the case when the practice does have higher operational costs than befits), "variable farming landscape" (the previous case, but just in the context of particular farms) and "learning and adjustment" (when the learning process is too expensive). This result shows that, for at least some farmers, some practices (but in special SR/BW given our results) are perceived to have a financial cost, which constrains their further adoption. This implies that farmers need more evidence of the profitability-enhancement potential of some no-cost practices under different scenarios, so as to be more aware of their costs and benefits in different specific contexts.

We also found that the barriers "risk and uncertainty", "unsureness about practicality" and "complex interactions" and "inadequate managerial capability" were quite relevant in our analysis. These cases reflect reasons farmers have to not expand the use of practices based on the risks, increasing difficulty, skills-necessity and managerial stress they involve. In other words, some no-cost practices are not being optimally applied because of their related risks and difficulty.

Among our investigated no-cost practices, "SR/BW" received the largest number of non-financial barriers to adoption –15 different ones. This finding shows that this practice is embedded with multiple factors that affect the decision-making of farmers from different angles, precluding the further use of this in New Zealand agriculture. On the other hand, the practice "Reduced N fertiliser use/replacing some pasture with lower N feed" received the lowest number of barriers in our analysis (only one), suggesting that the implementation of this no-cost practice should be less affected by non-financial barriers than the rest. In addition to the six no-cost practices, we also expanded our analysis to the identification of barriers for other practices that are not necessarily win-win options. Namely: the use of dairy bobby calves in the sheep and beef industry and the adoption of a "once a day milking" system. In these cases, we found that barriers in the typology category of "Market structure and intuitions" are more relevant than in the analysed no-cost practices (quotes and barriers listed in Table 8).

Interestingly, and in line with the literature review findings, we did not identify any of the barriers in the category "regulation and policy", but it was mentioned that to compel changes in farmers' behaviours regulation would help. The fact that GHG emissions can be an intangible and the impacts are long run, regulation can help to incentivise changes where scepticism can limit the adoption of mitigation practices. We also uncovered no evidence on the occurrence of other barriers listed in the typology of Jaffe (2017) – reflected by the blank rows in Table 10. Of course, the fact that these barriers were not mentioned by the interviewees it is not evidence of absence.

Our findings are relevant because they not only point to the need for further research to investigate the no-cost status of different practices in different contexts (as evidenced by the "arguably efficient" identified barriers), but also highlight how different non-financial barriers are directly affecting the broader use of the investigated mitigation practices. The identification of barriers to the adoption or expansion of no-cost mitigation practices is key for future policy planning and GHG mitigation research. With better knowledge of their effect on farmers' decision-making with regards no-cost practices, better communication and incentive mechanisms can be developed to reduce barriers and achieve a higher uptake of these practices and, consequently, reduce GHG emissions throughout New Zealand.

Lastly, it is important to mention that a lack of belief among farmers in anthropogenic climate change, or a lack of belief that their farming practices can have any effect on reducing climate change impacts, are large initial barriers to be overcome before they will consider adopting any GHG mitigation practices. Nonetheless, in most circles climate change denial is reducing and this evolving social norm will likely help shift farmers' attitudes. It is important that respected leaders in the agricultural sector acknowledge the reality of climate change and agriculture's significant contribution to it, and that they support and encourage changes to farm systems to reduce GHG emissions from agriculture.

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Appendix 1: Literature Review on Barriers to Adoption in New Zealand and Australian Farming Contexts

In the context of this study, we emphasise evidence looking at the adoption of no-cost mitigation options in agriculture in Australia and New Zealand (NZ). However, given the small amount of evidence (especially in the NZ context), we surveyed the literature beyond mitigation options. This appendix therefore includes research on the adoption of new technologies and/or practices in agriculture that are not necessarily no cost or aimed at reducing environmental impacts – evidence arising from the results of papers in which researchers were addressing the question of barriers to adoption. As seen below, however, some of the evidence discussed here is part of the by-products of agronomic research, i.e. researchers are giving limits to the uptake of the options they are studying.

In the following, we briefly describe – and in some cases discuss – the evidence found in the papers referenced in Table 1 for each listed barrier, with the exception of the "M" (Māori) references, which are described/discussed separately in Appendix 2. The numbers preceding each named barrier correspond with those listed in Table 1.

1.1 Modelling mismatch

Doole and Kingwell (2015) give evidence of a no-cost mitigation option in the context of nitrogen leaching from a representative dairy farm in the Waikato region of NZ. From farming simulations they show that farmers may initially use inefficiently imported supplement feed containing nitrogen. There thus exists a win–win situation where the farm may increase its profits and reduce its leaching, while reducing imported feed. However, the authors recognise that their simulations fail at encompassing the diversity of farming situations in NZ, so the option may not be no cost in some circumstances. Thus, as the same authors state, "Inherent in frontier estimation is the assumption that inefficient producers can replicate the management of efficient farms. This is problematic, given broad diversity in management skill, biophysical resources, and risk preferences among a population" (Doole & Kingwell 2015, p. 74).

1.2 Option value

Although this seems a clear and logical barrier to adoption, we did not find evidence directly related to this point in the literature for farms in NZ or Australia.

1.3 Variable farming landscape

This barrier relates to Jaffe (2017) distinctive barrier "variability and model incompleteness". Given the heterogeneity of farming systems, the average effect of a new practice (option) over different conditions may be negative even when the effect is positive under the "normal" (average) farming conditions. If the modelling does not consider the full distribution of effects, this could look like a barrier, which would replicate what occurred in Doole and Kingwell (2015) after they evaluated the practicability of their modelling exercise to adopt less imported nitrogen fertiliser.

Another element relates to farms' heterogeneity in NZ. Bewsell and Kaine (2005) interviewed 30 dairy farmers in four different catchments and concluded that a farmer's adoption of environmental best practice does not simply depend on his or her attitudes towards the environment. Rather, it is a complex process that must be specific to the farm system.

Smeaton et al. (2011) use a farm-scale model to suggest the existence of farming systems that both increase farm profits and have modest emissions. These systems include farming practices that decrease stocking rates, with change in their composition, or that increase the use efficiency of nitrogen fertilisers. According to these authors, such emission-friendly farming practices are not widely implemented because it is complex to do so and the biophysical characteristics (such as soil type) of some farms limit their intake.

In an Australian example, Rochecouste et al. (2015) investigate the drivers at play when farmers decide to adopt conservation practices. They conducted 31 field interviews to ask farmers for the underlying reasons of their non-adoption of conservation practices. The authors then grouped the responses and used causal loop diagrams to illustrate the global system wherein the decision is taken. Their study focuses on four practices that increase farm profitability and reduce GHG emissions: reducing tillage; retaining crop stubble; growing legumes; and controlled traffic farming (CTF, i.e. limiting soil compaction). For each case, farmers seem to pay most attention to the potential profitability induced by the practices, while assessing how their specific geographical or biophysical conditions may affect it. For instance, farmers who don't undertake reductions of tillage are those situated in high-rainfall areas, which reduces their interest. Similarly, some farmers did not adopt CTF because their topography was not perceived as suitable.

1.4 Learning and adjustment

Potential users might rationally conclude that the overall discounted present value of adopting the option is negative (Vanclay 1992; Vanclay 2004; Pannell et al. 2006).

These learning and adjustment costs fit with some of the principles Vanclay (2004) underlines as being legitimate barriers for non-adoption. Characteristics of the farming practice – such as its complexity, its divisibility into manageable parts, or its flexibility – will influence learning and adjustment costs. According to the author, the more complex the innovation is, the greater the resistance to adoption as too much additional learning is required (which also relates to the barrier "inadequate managerial capability", described below). In addition, the more divisible an innovation is into its component parts, the more likely it will be adopted because it allows implementing trials.

In line with this barrier category, De Silva and Forbes (2016) found for NZ horticultural growers that "lack of management time", "costs associated with implementation", and "compliance/paperwork" were the main barriers for further adoption of sustainability practices. We can understand these as belonging to the overall "learning and adjustment" barrier. The only limitation of this evidence is that the authors' conclusions are based on data from only 51 respondents out of a total of 2,000 online surveys sent to horticultural growers.

Van Reenen (2012) found that barriers to implementation were primarily resource based within the NZ sheep and beef farming context. The author specifically states that money is the biggest limiting factor, with time availability second. In her study, she states that farmers found it difficult to identify a financial return that would result from taking action. They were therefore reluctant to undertake action given the time involved. Although this study relates to a costly adoption and the barriers identified were mainly financial, time is also highlighted as an important barrier (an adjustment cost). This was the case even when farmers considered the intervention as beneficial, and so did not necessarily perceive it as costly.

In the Australian context, stronger empirical evidence is found in Abadi Ghadim et al. (2005), who set their adoption model of farming practices as a key variable. They measure this through the farmers' perception of what they learnt during the innovation's first trial. Thus, farmers with a high ability to learn from their first trial will have lower learning costs, whereas farmers with a lack of learning from the first trial tend to have a higher learning cost. Unsurprisingly, in the authors' probit model, the more the farmers perceived they learnt, the more likely it was that they decided to grow chickpeas (the option under consideration in the study). Thus, past experience at growing the crop increases the farmer's skills and their yield expectations, and as a result enhances adoption.

2.1 Awareness

In NZ, Rhodes et al. (2002) find a significant relationship between levels of exposure to relevant information and the actual adoption of riparian management practices. The study is based on survey data from 279 pastoral farmers (out of a total mail survey sent to 718 farmers) in the Otago and Southland regions of the country. They also find that the more relevant the information farmers receive, the greater their intention to implement riparian fencing or planting in the following year.

Cary and Wilkinson (1997) provide empirical evidence of this barrier for Australian farmers when they consider the adoption of conservation practices. They highlight the critical role played by information about the profitability and technical feasibility of new practices. Importantly, the better the information about likely long-term profit induced by the adoption, the more likely the farmer is to adopt the practice. Moreover, the environmental orientation of farmers and their awareness of the environmental problems at issue interacts with these economic variables. So, for a given perceived level of profitability and technical feasibility, an environmentally concerned farmer is more likely to adopt a conservation practice in comparison with a less concerned farmer. Thus, the adoption decision process is affected by both the availability of information and the farmer's attitude towards the information. As the authors discuss, this perception of the available information is therefore influenced by farmers' experiences and social norms.

It is worthwhile noting that the empirical evidence of Cary and Wilkinson (1997) considers the adoption of two conservation practices: planting of trees; and pasture improvement by sowing deep-rooted *Phalaris* pasture. These practices are obviously costly to implement but provide private benefits to the farmer by reducing soil degradation and erosion and increasing the efficiency of water usage. The practices also involve a positive externality as, when adopted, they reduce watershed pollution. The authors analyse the adoption of the two practices using a sample of 111 farmers in south-eastern Australia.

Also in Australia, Abadi Ghadim, et al. (2005) show that trialling is a way for farmers to become aware of the benefits of the options and thus enhances their adoption. Trialling reduces uncertainty and improves decision-making, although in their study farmers who tried a longer trial were more fit to revise their conceptions or judgements of the innovation.

In a survey of NZ pastoral farmers, Rhodes et al. (2002) also find evidence linking the awareness of financial subsidies for riparian fencing or planting with the farmer's intention to carry the practice out in following next year, exemplifying how an external driver (a potential subsidy) can encourage farmers to consider new options.

2.2 Unsureness about practicality

Llewellyn (2007) argues that the provision of more context-specific quality information (which can reduce learning costs) can help accelerate the adoption of new agronomic innovations in Australia. In addition, the author finds that participation in local farmer groups is a channel for such information. Although the study is more akin to a critical literature review on the importance of quality (and effective) information for the adoption of agricultural practices and does not provide empirical evidence of their claims, it summarises how information can alter the behaviour of farmers.

Also in Australia, Morgan et al. (2015) surveyed farmers with the aim of identifying the barriers to the adoption of mitigation options. Using different regression models they find that farmers with uncertain expectations on the practicality of the intervention and its capacity to increase profitability were less likely to adopt the no-cost option.

Dumbrell et al. (2016) propose an approach to identify the mitigation options farmers are more likely to adopt. They use a best–worse scaling method, a preference-revealing technique wherein farmers are repetitively asked to choose the best and worst mitigation options among a set of six. These rankings are balanced with farmers' socio-demographic characteristics and attitudes towards climate change. The set of mitigation options is given by carbon farming options, which refer to practices that increase carbon storage in soils. These options can have greater potential for crop farmers in the context of the study, which focuses on dryland cropping and mixed crop–livestock farmers.[20] Thus, the authors, using a total of 43 survey responses from farmers, highlight that knowledge of the co-benefits of the carbon farming options significantly increases their adoption.

2.3 Complex interactions

The findings of Dumbrell et al. (2016) relate to the barrier "complex interactions", as those farmers who are unsure about the interaction between the mitigation options (carbon farming options) and their (traditional) farming systems were less willing to adopt the former. For instance, the authors mention the resistance of farmers towards applying "biochar" because this practice does not readily fit within their existing farming system. The same thing occurred with planting trees, which were seen to compete with crops on water usage and nutrients. In contrast, the authors found that farmers were more likely to adopt practices that improve the soil quality, such as retaining stubble and rotational grazing (for mixed crop–livestock farmers); and retaining stubble, no-till cropping practices, and applying mulch (for cropping-only farmers). Farmers adopt these options as they perceive them as having positive interactions with their activities, i.e. there were positive correlations between production benefits and adoptions of the options. As the authors discuss, it appears important to demonstrate the profitability and the technical feasibility of different mitigation practices in order to clarify their interaction with yields and production and encourage their adoption.

3.1 Principal-agent or split-incentive problems

On this barrier, although non-agronomical, Jaffe and Stavins (1994) give a clear example:

> [I]f the potential adopter is not the party that pays the energy bill, then good information in the hands of the potential adopter may not be sufficient for optimal diffusion; adoption will only occur if the adopter can recover the investment from the party that enjoys the energy savings. Thus, if it is difficult for the possessor of information to convey it credibly to the party that benefits from reduced energy use, a principal/agent problem arises. (Jaffe & Stavins 1994, p. 805)

Even though this is a clear and widely discussed barrier in the technology adoption literature, we could not find farming evidence with a direct link to it in NZ or Australia.

3.2 Insufficient diversity of offerings

We did not find evidence of this barrier in our review.

3.3 Capital market failure

Although discussed by Harmsworth (2003) as a potential barrier for Māori communities in the uptake of permanent forest-protection schemes (see Appendix 2), there is no clear empirical evidence of this point as a barrier for adoption in NZ.

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[20] See Dumbrell et al. (2016, table 1, p. 31) for a list of the carbon farming practices discussed.

3.4 Supply chain failures

The evidence we found most closely related to this barrier in NZ was Botha et al. (2008), who illustrate how supply chain failures can be a barrier to adoption through the example of the supply of technical assistance played by agricultural consultants in NZ. However, as this study relates more to the next barrier, we discuss it below. No other evidence was found for this barrier.

3.5 Inappropriate or inadequate extension

A key NZ study looking at this issue is Botha et al. (2008). These authors led a wide empirical analysis mixing two case studies giving insights on the relationship between consultants and farmers; 18 phone interviews with consultants, researchers, and farmers; and a web-based survey alongside 149 consultants that questioned the consultants' influence on the adoption of pro-environmental practices. They found that farmers rely on the advice of private consultants for their production decision. When the study was carried out, in 2008, the authors found that consultants were more focused on productivity than on playing a significant role in informing farmers about important environmental (climate change) issues. The authors believe there are insufficient market forces that would lead consultants to deliberately advise farmers to adopt pro-environmental (mitigation) practices. The authors even claim that when consultants advise farmers on environmental issues, their advice is a result of the farmers' demand and not a deliberate choice. One possible issue is the gap between agronomic researchers and consultants, limiting communication of the most recent research. In some way this evidence also relates to the "informational" barrier, but the difference here is that it is an external factor, as farmers are indeed seeking information from consultants, but the latter are not providing it adequately.

Also in NZ, Brown and Bewsell (2010) support the existence of heterogeneous learning needs across farmers who challenge the implementation of extension programmes. These learning programmes are commonly devised with a "one size fits all" approach that does not support the learning needs of some farmers. Using in-depth interviews with 15 sheep and beef farmers and a mail survey involving 1,000 sheep and beef farmers (with a 25% response rate), the authors first acknowledge the learning needs of farmers when considering the use of computer-based feed planning. They statistically identify three homogeneous segments of the population using cluster analysis: farmers who informally plan feed and who are interested in furthering their computer skills; farmers who have used both informal and formal feed plans; and farmers who formally use feed planning and who are interested in learning about other feed planning technology. Although the authors warn that their approach is consuming in terms of resources, they also claim that it allows a better understanding of the skills that are needed in order to implement a practice and which farmers lack these skills. Thus, Brown and Bewsell argue for designing a targeted skill workshop in order to answer the needs of farmers more accurately, which would in turn increase the impact of extension programmes.

In a similar context, Sewell et al. (2014) investigate the learning process of NZ pastoral farmers considering the adoption of improved management practices for herb-mix pastures (such as chicory, plantain, and red and white clover). The paper is related to education theory and does not directly refer to barriers to adoption. It does, however, give evidence of factors that negatively affect the farmers' learning process, which leads to rejection of the innovation. They conducted a case study consisting of an extension programme workshop for 18 farmers and agronomists promoting the adoption of herb-mix pastures. The authors' intention is to inform the design of the extension programme through observations during the workshop and semi-structured interviews with the farmers. They find that three key factors significantly promote the learning process of the farmers: a trustworthy relationship between the farmers and the scientists; the possibility of conversing in small groups with the scientists; and the replication of different activities or experiences with which farmers can directly identify. This highlights the gap between academic or extension agents' techniques and farmer practice as a barrier to learning.

In Australia, the approach led by Morgan et al. (2015) allows us to draw similar conclusions. Although Morgan and colleagues do not provide direct evidence of this barrier, they do state that among the four farmers' profiles (which they describe based on their non-random sample of 551 surveys), two seem to pay attention to contrasting extension programmes. The "non-green dismissive" profiled farmers, who disagree on the potential negative impacts of climate change and have a significant lack of environmental interest, are not receptive to communication programmes underlining environmental benefits from mitigation options and prefer communication based on the financial benefits of their adoption. On the other side, the "green adopters" are more receptive to management programmes that highlight the environmental co-benefits from mitigation options.

Kaine et al. (2005) review an extension programme that aimed to improve irrigation management in Victoria's Goulburn Valley in Australia. This programme failed to achieve the original goal, because the main motivation for growers to change irrigation management was communicated as saving time and improving management flexibility, rather than reducing water use or increasing water use efficiency. This suggests that an inappropriate extension programme may serve as a crucial barrier to adoption.

4.1 Safety or other verifications

We did not find evidence of this external barrier on adoption in the NZ and Australian literature.

4.2 Environmental regulation

As with "safety or other verifications", we did not find evidence of this external barrier in the agricultural literature in NZ or Australia. It is likely that this was because our search was looking for evidence or discussion of barriers, so we may have missed studies discussing environmental regulation from only an institutional point of view.

4.3 Demand for new regulatory regime

We did not find evidence of this barrier on adoption in the NZ and Australian literature.[21]

4.4 Inadequate/inappropriate regulation

We did not find evidence of this barrier on adoption in the NZ and Australian literature.

5. Risk and uncertainty

Rochecouste et al. (2015) evidence this barrier in their study of drivers for growing legumes in Australia. Growing legumes on a rotational basis retains nitrogen in the soil and allows a boost to future grain yields, thus reducing the need for fertilisers. However, farmers perceive the growing of legumes as highly seasonally dependent compared to other crops – for instance, cereals obtain better yields than legumes during dry years. At the same time, this decision is balanced by the level of input prices and output prices. If fertiliser prices are high, farmers may assign a higher value to the benefits from growing legumes, which will depend on legume prices.

In addition to possible cost–benefit variation over time periods, there may also be a more fundamental uncertainty about the magnitude of the overall net benefit of an adoption. Positive net benefit may depend on assumptions about the performance of the option or about average prices for inputs or outputs that are inherently uncertain. If this uncertainty is asymmetrically inclined towards costs, then adoption of the option may systematically increase the farmer's overall risk, thus discouraging adoption even if the expected value of the consequences of doing so are non-negative.

Given these considerations, different costs and benefits should be included when calculating the present value long-term profitability of adoption. However, if future benefits (e.g. savings in labour costs) are more uncertain than costs (e.g. initial investment expenditure), then a risk-averse purchaser would rationally discount those uncertain future savings below the expected value or most likely value. This could result in an investment that appears profitable under the most likely future conditions to appear unattractive once the risk is taken into account (Jensen 1982).

The barrier "risk and uncertainty" relates directly to the aforementioned Abadi Ghadim et al. (2005) research looking at chickpea crop adoption in Australia. From a survey of 114 farmers facing a decision of whether to grow chickpeas or not, they developed a probit model illustrating which variables had a statistically significant effect on the probability of adoption. They find the

[21] An example of this barrier is the application of dicyandiamide (DCD) to grazed grassland soils, which can reduce emissions of nitrous oxide. Even though the OECD established that DCD use is close to no cost (MacLeod et al. 2015), the NZ dairy industry voluntarily stopped its use in 2006 due to customer concern over low residue levels in milk products. In this case, a proper international regulatory regime, based on scientific evidence that would have allowed a certain safe level of DCD in milk products, could have prevented the withdrawal of a mitigation option from farm systems in NZ.

measure of farmers' risk aversion is one of the main predictors of adoption. Specifically, risk aversion correlates with lower rates of chickpea cultivation by farmers and has more effect as the growing area and risk perception of the yields of chickpeas increase. Thus, the perceived risks outweigh the potential benefits introduced by the diversification of growing chickpeas.

Funk et al. (2014) adopt a land-use model to study the economic and environmental benefits of incentivising the conversion of pastures to native forest through the reception of carbon credits. Although planting forests is not "no cost" per se, the authors highlight that carbon markets can bring significant benefits to farmers to incentivise them into planting forests. However, their discussion shows that the potential benefits from adoption are strongly affected by market uncertainties about the price of carbon, and by policy uncertainties, which could lead to a collapse of carbon markets or substantial changes in the price of carbon. Similarly, the interviews conducted by Cooper and Rosin (2014) with NZ dairy farmers led to similar conclusions:

> Because the price of emissions units are set in the market, and the price of emissions units in both NZ and other trading schemes has experienced significant fluctuations, farmers face an irresolvable uncertainty if they attempt to craft an "economically rational" response to the ETS. Across a three year period from 2009 to 2012, the estimated market price of NZ units ranged from NZ$25–$50 in government scoping models, to an actually traded price of NZ$2.03. Responses to the ETS that were economically rational at NZ$25, were decidedly irrational at NZ$2. Beyond their opposition to the notion of regulating agricultural GHGs, farmers found the inability to create farm management plans to respond to the new regulation even more problematic. (Cooper & Rosin 2014, p. 397)

In their best–worse scaling study, Dumbrell et al. (2016) show that policy uncertainty and carbon price uncertainty are factors disincentivising farmers from adopting carbon farming activities. For instance, the opportunity to sell carbon credits is not perceived as beneficial when adopting a carbon farming activity. In this study, farmers paid more attention to improvements in soil quality and the reduction of erosion induced by these practices.

6. Externalities

An example of this barrier is given when a farmer who leases land from another owner may not be able to capture all the long-term benefits of changes in land-use practices. Another example is when a farmer may, for historical reasons, get irrigation water for free, and so does not include water savings as a benefit. In these cases, a fundamentally no-cost option may not appear as no cost from the perspective of the farmer decision-maker (Jaffe 2017). Although these examples of an "externality" barrier are quite common in agriculture, we did not find such evidence in the NZ literature.

7.1 First-cost bias

In the NZ context, Corner-Thomas et al. (2015) provide evidence that the larger the farm, the more able it is to absorb the fixed cost of the adoption of new technology. Their research objective was to identify the characteristics of farms that uptake profitable management tools. To do so, they conducted 962 surveys with NZ sheep and beef farmers. They then assessed the effects of a farm's characteristics on the adoption by logit regression. Farm size is a significant variable, as larger farms use more tools on average. The study reports that farm size may be interpreted as a proxy of the ability of the farm to overcome significant upfront costs when adopting a practice.

In Australia, Rochecouste et al. (2015) underline that some farmers place high consideration on the capital cost requirements for avoiding soil compaction, even though limiting compaction will allow them to have increasing yields in the future.

7.2 Salience bias

We did not find any studies in NZ evidencing the "salience bias" barrier in agriculture.

7.3 Loss aversion

We did not find a NZ study directly investigating this barrier. In Australia, Raymond and Spoehr (2013) find that landholders who reject or are unsure about human-induced climate change are less likely to believe a winter–spring drying trend is possible, although this study does not focus on barriers and uses loss aversion in a more abstract way. The authors argue that landholders display loss aversion associated with the framing of terms, i.e. a human-induced climate change could have a more severe adverse effect on farm incomes and hence a higher subjective loss value.

7.4 Inadequate managerial capability

In NZ, Nuthall (2006) provides evidence of the need in critical managerial skills for tackling farming activities. The author undertook a mail survey among 708 professional consultants and a set of 2,300 randomly selected farmers (with effective response rates of 43.5% and 41.1%, respectively). A wide set of skills common across all farm types are considered critical by farmers and consultants. These skills are related to people management, information gathering and its use in planning, and risk management. Nuthall suggests training packages should target those skills in order to match farmers' interests. Moreover, adopting new farming practices would require training in certain skills that farmers believe to be important (e.g. forecasting, accurate and complete observation, and acting decisively). Some mitigation options may be more dependent on these capabilities, so training may be a prerequisite to a successful adoption.

In the Australian context, Morgan et al. (2015) provide a similar argument. They surveyed 551 Australian farmers, illustrating how some typical patterns of perceptions towards mitigation options can differ. The authors build four statistically consistent psychological profiles of farmers, based on significant average differences concerning "psychological variables" characterising attitudes towards climate change. Although they do not randomly select their sample of farmers, they highlight aspects of farmers with different key variables that summarise the farmers' decision process in relation to adoption. Using regression models that aim to explain the causes of the adoption of mitigation options, the best prediction of adoption is a farmer's belief in "self-efficacy". In other words, farmers that are strongly (weakly) confident in their ability to manage mitigation options are more (less) likely to adopt mitigation practices.

The work of Abadi Ghadim et al. (2005) also fits this barrier category. These authors measure (to some extent) the learning ability of farmers by studying their perception of the first trial of an innovation and their related learning. As discussed previously, their econometric analysis finds that the greater the perception of learning in a farmer, the more likely he or she is to adopt the innovation.

7.5 Social norms and prestige

Rochecouste et al. (2015) highlights the fact that the implementation of tillage reduction in NZ (the adoption they study) is apparently mainly driven by the examples provided by peer farmers who demonstrated the potential gains of this practice. Thus, in this case, peer example and a "follow the leader" attitude can be attributed in some extent to the social prestige barrier. If a farmer with relative prestige in a community rejects a farming practice, it is likely that others will follow this attitude.

7.6 Habitual behaviour

Farmers may be reluctant to change traditions or old ways of doing things (Rodriguez et al. 2009). More generally, farmers may perceive on some level that new technologies or practices would be helpful, but just don't want to be bothered or inconvenienced by having to deal with them. On some level, this barrier could be seen as a mixture of the effects of habit and low salience, but relates more directly to the farmers' habitual behaviour.

In this final point, De Silva and Forbes (2016) find that showing no interest is one of the important barriers stopping growers in the NZ horticulture industry from carrying out additional sustainability practices. However, it is not clear in their study if showing no interest is habitual behaviour, which can be a norm that goes beyond adoption, or a disincentive to the adoption of new farming practices.

7.7 Trust or credibility

Trust has been shown to be a key behavioural aspect in adoption, as even though farmers can have the necessary information and skills to adopt an option in a non-costly way, they may still not adopt if they find the source of information untrustworthy (Carr & Tait 1990).[22]

Similarly, Brown et al. (2016) provide contextual evidence for NZ, where they say farmers are more likely to implement new technologies and practices if they have first seen their successful application elsewhere. The authors also state that farmers do not trust the

[22] Loosely speaking, trust may be viewed as a lack of quality information and hence could potentially fall under the barrier category "Information".

government as an agent of adoption information, but tend to rely more on fellow farmers regarding information about different land practices and environmental practices that they are considering for adoption. In order to overcome this trust barrier and encourage the transmission of information from early adopters or from experienced farmers who have successfully applied new management practices, Brown and colleagues suggest that regional councils could employ these farmers (who they define as "innovators") to spread the knowledge of benefits that could be obtained from adopting new practices/technologies. However, as the authors discuss, the networks of these "innovators" are also important, as ideally they would spread knowledge as much as possible. They define farmers with large networks as "connectors".

Empirically, Brown et al. (2016) analyse these connectors and innovators using 1,549 observations from (countrywide) data originated by the Survey of Rural Decision Makers conducted in 2013 by Landcare Research.[23] Using these data and different econometric specifications, the authors look at what characteristics define innovators and connectors in order to better identify which farmers need to be targeted so that the knowledge of "pro-environmental farming practices" can be spread effectively across NZ. They find that innovators and connectors tend to be young, male, highly educated, and financially robust operators on large, diverse farms. The authors also find that only education and financial robustness predict trust in the environmental performance information provided by regional councils, which leaves councils with fairly limited information for identifying effective advocates of adoption practices and avoiding knowledge externalities. In a study that also uses data from the Survey of Rural Decision Makers, Small et al. (2016) show how farmers in NZ (at least those surveyed by this instrument) have more trust in scientists and other farmers than in the central, regional, and district governments. Seeing a practice successfully demonstrated on other farms is important in helping some farmers adopt new practices.

It is worth noting that the behavioural biases described and discussed here relate to ideas in the theory of planned behaviour (TPB), one of the dominant psychological models of human decision-making (Ajzen 1991, 2005). The TPB considers that decisions regarding any new practice are determined by three fundamental beliefs: behavioural beliefs, which shape the attitudes (positive or negative) towards the behaviour; normative beliefs, which determine the importance of subjective norms that may approve or disapprove the implementation of the behaviour; and control beliefs, which help form the perceived control over the behaviour. Attitudes towards the behaviour, subjective norms, and perceptions of behavioural control jointly constitute the central determinants of an individual's intention and action to perform the given behaviour.

[23] For more references on this survey, see http://www.landcareresearch.co.nz/science/portfolios/enhancing-policy-effectiveness/srdm/

Niles et al. (2015) have developed a novel approach, which couples Liebig's law of the minimum in ecology with the psychological distance theory, to address how farmers' past experiences with climate change and the regional biophysical characteristics of their farms (e.g. water in Hawke's Bay and temperature in Marlborough) together influence the adoption of climate adaptation strategies. The study was conducted using a telephone survey of 490 farmers in the Hawke's Bay (n=177) and Marlborough (n=313) regions.

In the Australian context, Fielding et al. (2008) use the TPB approach to explore farmers' decision processes for adopting conservation practices (riparian management). They conducted two surveys on horticulturists in Queensland, with 609 and 444 useable respondents. The surveys were designed to assess the importance of the three level variables in the decision process (attitudes, subjective norms, and perceived behavioural control), and to identify which of these plays the most significant role in the adoption of riparian management practices. Past behaviour is used to proxy attitudes (whether farmers were currently engaging in any activities to manage the riparian zones on their farm and with what level of effort). Subjective norms are measured by asking farmers whether they would expect their peers to approve of their decision to adopt the new practice. Perceived behavioural control is assessed by asking farmers about their perception of their control over managing riparian zones on their farms. The study is completed with other variables such as farmers' perception of their identity. The authors use a standard ordinary least squares technique to assess the role and the magnitude played by each variable. They use a self-reported measure by farmers (on a seven-point Likert scale of whether they would be likely or not likely to adopt the conservation practice) as the dependent variable. Among their findings, it is worth highlighting that farmers with negative perceptions of their subjective norms are less likely to adopt the practice. Attitudes and perceived behavioural control explain the most significant part of the variance of adoption. Thus, as the authors state, "when landholders had more positive attitudes towards riparian zone management, had a greater sense of control over managing their riparian zones and when they perceived greater support from their landholder community, they were more likely to intend to manage their riparian zones" (Fielding et al. 2008).

Appendix 2: Literature Review on Barriers to Adoption in Māori Farming Context

The main barriers found in the sparse Māori literature are "arguably efficient", "information", "market structure and institutions", "regulation and policy", "risk and uncertainty", and "behavioural factors". Given the lower number of studies than those discussed in Appendix 1, we subdivide this appendix by barrier categories (as shown in Figure 1).

Arguably efficient

Modelling mismatch appears when the assumptions considered in the model do not match with the farm's reality (Jaffe 2017). Harmsworth et al. (2016) analyse the value of critical source area (CSA) management at farm and catchment scales to support the management of iwi/hapū (tribe/sub-tribe) values and achieve iwi/hapū aspirations. They evaluate the role of models and tools at farm and catchment scales to inform iwi/hapū planning and decision-making. One of the conclusions of this study is that although modelling tools offer knowledge and information to plan and guide decision-making processes, Māori stakeholders are wary about these tools for the assumptions and simplifications made of a complex system.

Information

Jaffe (2017) asserts that adoption can be affected by restrictions on information, such as lack of awareness or complex interactions. In a study that set out to identify features of climate change adaptation, mitigation, and business opportunities for Māori-owned land, Harmsworth et al. (2010) conclude that even though Māori stakeholders show a high level of interest in climate change opportunities,[24] the lack of knowledge about these opportunities affects their ability to make and implement informed decisions. The authors also highlight the importance of understanding Māori land characteristics and governance, and providing access to research, technology, and innovation, as critical factors to increase Māori participation or adoption of these opportunities.

Market structure and institutions

Because different actors can be involved in the decisions about Māori land management, situations such as principal-agent or split-incentive problems can inhibit the adoption of mitigation options (Jaffe 2017). Based on a case study analysis, Funk (2009) provides a number of factors that are present and influence the decision-making processes of allocating land to forestry and moving into carbon farming (or provision of carbon credits). He concludes that the decision to become involved in carbon farming can be difficult to reach because different actors (e.g. owners, managers, trustees) participate at different points along the decision-making

[24] The climate change opportunities studied and prioritised were: carbon-forestry sink, land-use change, renewable energy, energy efficiency, nutrient use and budgets, measurement technologies, anaerobic digestion, methane, and nitrous oxide abatement (Harmsworth et al. 2010).

process.[25] In another case study analysis, Journeaux et al. (2016) established a network of 29 Māori farms to identify key characteristics and the effect of Māori entities (e.g. trusts, incorporations, partnerships, or companies) on GHG emissions. They conclude that investment decisions and farm performance are largely driven by the capability of governance and management. On the other hand, studies have indicated that investment on Māori land can be negatively affected by capital constraints (e.g. Kingi 2008; Ministry of Agriculture and Forestry (MAF) 2011; Daigneault et al. 2015; West et al. 2016).

Regulation and policy

The complex institutional arrangement that governs Māori land and the existing regulation can be potential disincentives to the adoption of new options.[26] Kingi (2008) holds the view that Māori trusts and incorporations that aspire to succeed commercially might have to deal with uncertainty about their legal capacity to conduct their affairs as they are subject to the scrutiny of the Māori Land Court.

Risk and uncertainty

Māori landowners' experiences and opinions on carbon farming strategies have been documented in a few studies that also report concerns that could prevent effective implementation of existing programs for utilising forest carbon credits (Carswell et al. 2002; Harmsworth 2003; Dickson et al. 2009; Funk & Kerr 2009; Harmsworth et al. 2010; Bruce 2012; Cronin et al. 2012). These concerns include retention of Māori landownership and control, liabilities, penalties, and commitment to long covenant periods.

Behavioural factors

Jaffe (2017) suggests that behavioural factors can represent a barrier for adoption when cognitive biases push agents away from rational profit maximisation predictably or systematically. Because Māori land is considered a basis of identity, the decision-making process regarding the use or management of Māori land requires a balance among sociocultural, environmental, and economic imperatives (Durie 1998; Dewes et al. 2011; Kingi 2013; Mead 2016). West et al. (2016) note that investment decisions take into account historical factors, acknowledgement of the past owners, and the welfare of future generations. The legacy for future generations of landowners plays an important role in the decisions of current landowners to either adopt new technologies or invest in infrastructure.

Adoption of an option may require some specific skills. King et al. (2010) mention the necessity of assessing the capability within the Māori agricultural sector to adapt as a critical

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25 Funk (2009) documents a case study where the negation of contract of carbon farming was declined due to lack of support of one of the members of the trust, although the proposal was strongly supported for the lessees who would manage the land and who felt strongly that carbon farming would play a valuable role on some areas of the by.

26 The current institutional arrangement that governs Māori land has been inherited and is a mixture of customs, traditions, and the results of Crown legislation introduced in 1862 (Kingi 2004). As a result, Māori landownership has been passed on through successive descendant generations of the former owners, and individual interests in the same block of Māori land have been registered, creating multiple owners and interests (Kingi 2008).

element in identifying the industry's risk from a changing climate. Similar ideas are highlighted by Harmsworth et al. (2010), who express the necessity for building capability within Māori organisations to help them adopt and implement mitigation options and take advantage of climate change opportunities such as a carbon forestry sink.

Social norms play a key role in the adoption of certain options. Awatere et al. (2015) highlight the importance of Māori cultural values such as kaitiakitanga, manaakitanga, and whakatipu rawa when communities make decisions on resource management planning and meet environmental, cultural, and social objectives.[27] Similarly, Harmsworth et al. (2010) state that it is critical to put "mitigation options" into a kaupapa Māori or Māori values and aspirations framework that Māori can understand and identify with. Some mitigation options do not work within long time frames (in line with the Māori world view) to ensure intergenerational equity and provide long-term benefits.

The level of trust in the source of information regarding options can affect their adoption. Some Māori groups have expressed a distrust of policy, initiatives, and programmes led by central or local government (Harmsworth, et al. 2010). This can be a result of the historical relationship between Māori and the Crown (Reid 2011). Māori are generally wary of government schemes, especially those that introduce penalties at the end of the contract agreement and take away rights of control and ownership (Harmsworth 2003).

[27] According to this project, kaitiakitanga refers to Māori sustainable resource management; manaakitanga is a principle that reflects reciprocity of actions to the environment, the community, and other people; whakatipu rawa is a concept concerned with growing the asset base, retention of Māori-owned resource, and effective use of these resources for beneficiaries and future generations (Awatere et al. 2015, p. 11).

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