Methane and Metrics: From global climate policy to the NZ farm

Zack Dorner[1] and Suzi Kerr[2]

Motu Working Paper 15-11

Motu Economic and Public Policy Research

August 2015

[1] Motu Economic and Public Policy Research and Monash University

[2] Motu Economic and Public Policy Research

Author contact details

Zack Dorner
Monash University
zachary.dorner@monash.edu

Suzi Kerr
Motu Research
suzi.kerr@motu.org.nz

Acknowledgements

A huge thank you to Hugh McDonald for his direction and assistance throughout, and to Andy Reisinger and Adolf Stroombergen for their very helpful comments during the drafting process. This work was done during an internship at Motu as part of the "Coordination and Cooperation for Effective Climate Policy Design and Implementation" programme funded by the Ministry for Primary Industries Sustainable Land Management and Climate Change Fund. All opinions, errors and omissions are the responsibility of the authors.

Motu Economic and Public Policy Research

PO Box 24390
Wellington
New Zealand

Email info@motu.org.nz
Telephone +64 4 9394250
Website www.motu.org.nz

Abstract

Stroombergen and Reisinger's (2012) modelling suggests global pricing of all greenhouse gas (GHG) emissions, including agricultural emissions, would be beneficial for the New Zealand economy, with higher GHG prices leading to greater economic benefit. Though this inference may seem counter-intuitive for a country in which agriculture is economically important, when the effects of GHG charges flow on to global commodity prices, the rise in global prices more than compensates NZ for the costs of our GHG emissions. These conclusions rest on a single set of models and several assumptions; however, the broad direction of the conclusions makes sense given the relatively low GHG emissions intensity of agriculture in NZ and the high importance of global commodity prices for NZ's economic fortunes. In this paper we investigate the implications of Stroombergen and Reisinger's (2012) results for a model NZ dairy and model NZ sheep and beef farm. We consider three climate policy scenarios that differ by whether agricultural emissions are included and priced globally, and in NZ. We find that NZ farmer interests generally align with NZ's economic interests, though farmers are more greatly affected by differing international policy scenarios compared with the NZ economy as a whole. We find that the impact of the choice of metric (that is, how agricultural emissions are traded off against carbon dioxide emissions) is minor, especially when compared with the differences between international and domestic policy scenarios. On balance, our results suggest that long term, the best scenario for NZ and our farmers is to fully price global agricultural emissions within an international climate change agreement that allows NZ farmers to exploit their competitive advantage.

JEL codes

Q12, Q18, Q54, Q57.

Keywords

Climate change policy, methane, metrics, New Zealand, agriculture, greenhouse gas, economic impact, dairy farm, sheep and beef farm.

Contents

1. Introduction

As the world approaches the important climate change conference in Paris in December of this year, it is worth looking at how global climate policy for agriculture might affect New Zealand's agricultural industry. The importance of agriculture to NZ's economy and our reliance on international commodity markets is particularly salient given the recent plunge in global dairy prices. In public debates it is often argued that the NZ agriculture sector should not face the cost of their emissions given their important role in the economy, the apparent lack of mitigation options available to farmers, and the fact that NZ farms are already very efficient from a climate change standpoint. However, these arguments do not necessarily stand up when examined more closely. Arguably it is in NZ's economic interest for agricultural emissions of methane and nitrous oxide to be treated in the same way as other emissions in any global climate policy agreement. This is partly because an effective global climate policy on agriculture would favour efficient producers of agricultural products, like NZ. Furthermore, research has found that NZ farms do have affordable mitigation options available to them (even without using nitrification inhibitors) and including agricultural emissions in global climate policy will reduce global costs of mitigating climate change (Adler *et al.* 2013; Anastasiadis and Kerr 2013; NZAGRC 2015; Reisinger *et al.* 2013; Reisinger *et al.* 2015; Reisinger and Ledgard 2013; van Vuuren *et al.* 2006). New Zealand, like other countries, would benefit from the lower CO2 prices that come from more cost-effective global mitigation.

This paper proceeds as follows. We first consider the implications for NZ of whether agricultural emissions are included in global climate policy or not and discuss how the measurement unit of agricultural emissions (the "metric" used) is also an important consideration. We do this by summarising the main results from Stroombergen and Reisinger (2012) (hereafter referred to as S-R),[3] with a focus on methane. While the scenarios considered are extreme versions of what is likely to happen, they allow us to understand important ideas about the impacts of global climate policy on NZ agriculture, and the interactions between domestic and global policy choices. In the second half of the paper we extend this modelling by estimating the impact on the profits of model dairy and sheep and beef farms. This extension is important as it does not necessarily follow that what is in the national economic interest is also in farmers' interest. We conclude with a discussion of the results and their implications.

[3] Stroombergen and Reisinger (2012) is a summary of Reisinger and Stroombergen (2011). Some of the detail contained in this paper may not be in their 2012 paper, but in their 2011 report instead. Also see Reisinger *et al.* (2013).

2. Summary of Stroombergen and Reisinger

Before summarising S-R, it is useful to revisit some basic facts about agricultural emissions. Livestock agriculture is directly responsible for two main greenhouse gases (GHGs) – methane and nitrous oxide, both of which are much more potent than the main GHG, carbon dioxide (CO2). Methane is the second most important GHG globally, contributing about six times as much to current warming (radiative forcing)[4] as nitrous oxide and over half as much as CO2 (IPCC 2013b). Agriculture emits CO2 only indirectly, through its use of energy and products generated by fossil fuels, and in some countries, deforestation. In New Zealand, lifecycle analysis indicates that currently, CO2 makes up only about 10% of the total emissions generated for the production of dairy products (Reisinger and Ledgard 2013). Given the importance of non-CO2 GHGs, including them in global climate policy could lower the costs of meeting a climate change mitigation target by 30-40% (van Vuuren *et al.* 2006) or even more if ambitious climate goals are considered, such as limiting warming to 2 degrees as is now agreed under the UN Framework Convention on Climate Change (UNFCCC) (Gernaat *et al.* 2015; Reisigner *et al.* 2015). Agriculture produces around half of non-CO2 GHGs globally; roughly two thirds of the methane produced by agriculture is produced by ruminant livestock. Sixty percent of global nitrous oxide emissions are from agriculture (Clark *et al.* 2011; Eckard *et al.* 2010; IPCC 2014). Given the prominence of livestock agriculture to NZ's economy, about 30% of our GHG emissions are methane and about 18% is nitrous oxide,[5] which is a very high proportion compared with the rest of the developed world (Clark *et al.* 2011). Methane emissions are quite sensitive to which metric is chosen as an exchange rate between GHGs, therefore the focus of the discussion in this paper is methane, though some conclusions may also apply to nitrous oxide.

For a brief summary of S-R's modelling approach, see Appendix 1. It is worth noting here that they integrate a number of mostly economic models, none of which take account of the impacts of climate change. Furthermore, due the complexity of the models and scenarios, the results presented here are intended to be indicative of the direction of changes between the scenarios, rather than accurate forecasts of the future.

[4] See the discussion on metrics below for a definition of radiative forcing.
[5] Using the GWP metric.

Table 1 Summary of the scenarios.

Scenario	Global policy	NZ policy
All in this Together	All emissions, including agriculture, face the same price.	All emissions priced at global price; agriculture only pay for 10% of their emissions in 2015, increasing by 1.3% per year. NZ responsible for all types of emissions in mitigation target of 15% below 1990 levels by 2020.[6]
Agricultural Conundrum	All emissions are priced except agricultural emissions, but countries are still accountable for those emissions.	As above.
Agriculture Out	All emissions are priced except agricultural emissions, and countries are not accountable for those emissions.	All emissions are priced at the global price except agricultural emissions. NZ is responsible for all emissions in mitigation target of 15% below 1990 levels by 2020, except agriculture.
Baseline	No emissions are priced (for comparison only - no damages from climate change are modelled).	

2.1. Policy scenarios and their implications for NZ

We describe S-R's three main scenarios in Table 1, renaming them for simplicity. They consider three global policy settings - agricultural emissions are included and mitigated (*All in this Together*) and agricultural emissions are not mitigated, with two contrasting assumptions. One is that they are included in agreements but no action is taken to actually mitigate them (*Agricultural Conundrum*) and the other is that agricultural non-CO_2 emissions are not counted at all (*Agriculture Out*). For NZ, we have to meet a mitigation target by 2020. This target includes our agricultural emissions (*All in this Together* and *Agricultural Conundrum*) or it does not (*Agriculture Out*). Other than variations in the treatment of agricultural GHGs, the three scenarios assume economically efficient climate policy globally. Greenhouse gas emissions are priced in NZ at the global price, though agricultural emissions are priced as originally proposed under the Emissions Trading Scheme (NZETS) - with a 10% liability in 2015, increasing by 1.3% per year, and unpriced in

[6] Stroombergen and Reisinger also model these scenarios in 2050 with a 50% target for NZ, which is the government's current stated target for that year. Their 2050 results for NZ are an exaggerated version of their 2020 results, hence we discuss their 2020 results only.

Agriculture Out.[7] All scenarios are modelled to meet a 450ppm[8] limit for the atmospheric concentration of CO_2 equivalent[9] at 2100. This target is generally considered to be consistent with the international aspiration to limit global warming to 2°C.

Figure 1 The effects on prices of agricultural emissions being priced and not being priced in 2020 with a 450ppm target for 2100, using the GWP metric (S-R).

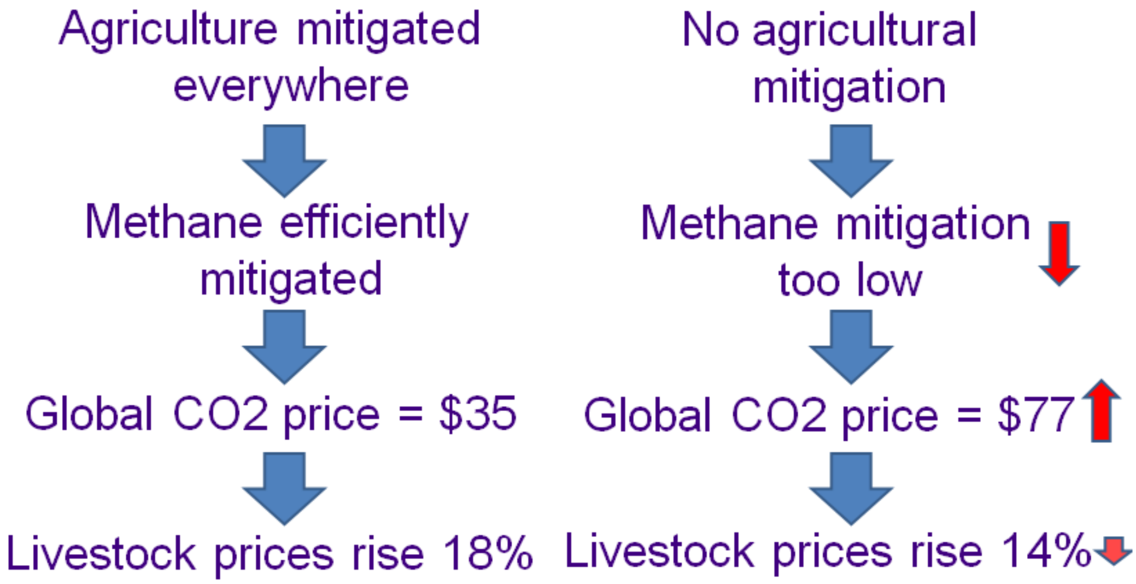


Figure 1 shows how the two global policy scenarios impact the CO_2 price (using the GWP metric - which we will discuss shortly) and an index for livestock commodity prices. When global agricultural methane is excluded, around half the sources of methane and nitrous oxide that could be mitigated are no longer mitigated. Therefore, other sources of GHGs must make much deeper cuts, more than doubling the CO_2 price, thus increasing global mitigation costs by 16 to 56%. Livestock commodity prices rise 14% over the no mitigation baseline prices by 2020, due to competition for land from reduced deforestation, forestry and biofuels, and also the CO_2 emissions associated with agriculture. Global livestock commodity prices rise instead by 18% when agriculture must pay (globally) for its methane and nitrous oxide emissions. The 14% price rise in global livestock commodity prices *without* mitigating agricultural non-CO_2 emissions

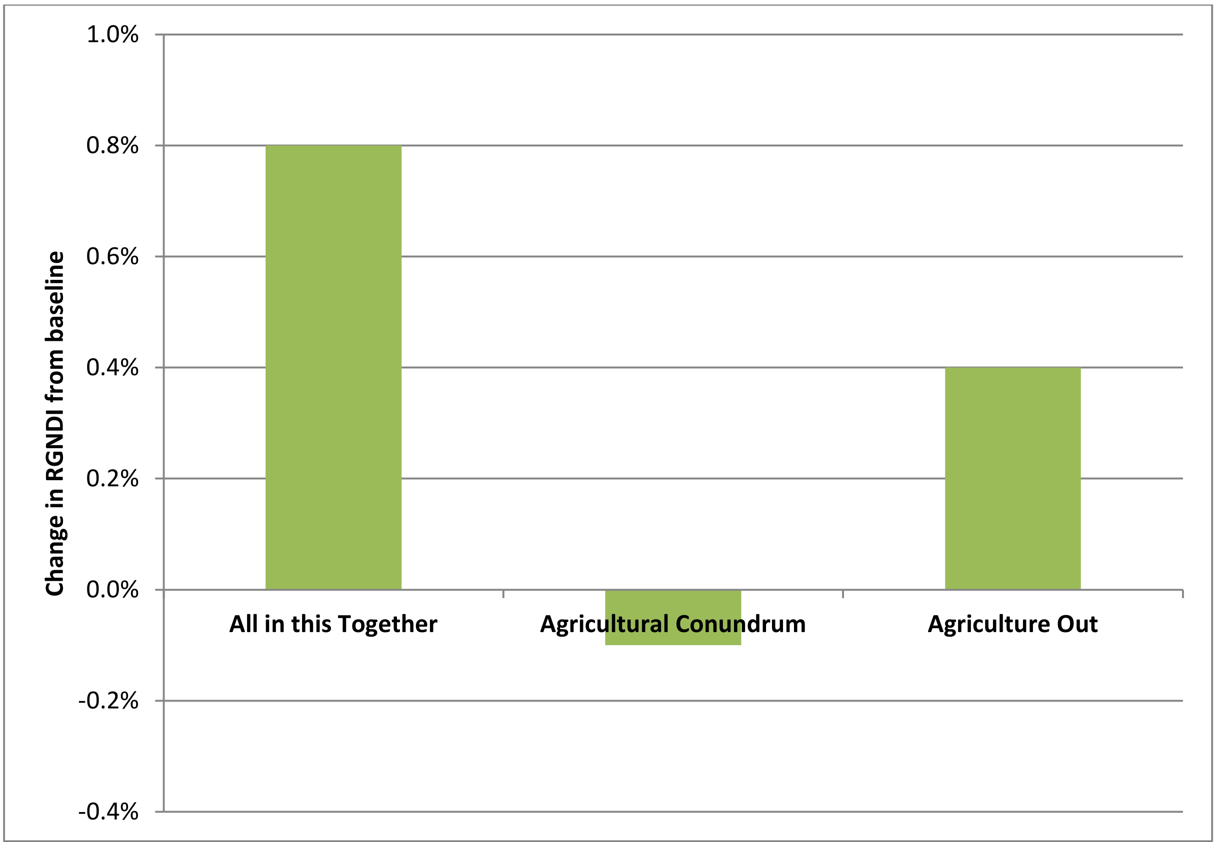
[7] Current NZETS policy is to include agriculture only when the government determines that farms can be reasonably expected to mitigate, and trading partners make more progress on mitigation in general (see https://www.climatechange.govt.nz/emissions-trading-scheme/participating/agriculture/. Accessed August, 2015)

[8] Ppm stands for parts per million. Therefore, an atmospheric concentration of 450ppm of CO_2 means that out of every 1 million particles in the atmosphere, 450 are CO_2.

[9] CO_2 equivalent, meaning the same radiative forcing as this level of CO_2, even if it is composed of various GHGs.

demonstrates that efficient global CO2 mitigation alone is good for NZ's agricultural industry, and there is only a further 4% increase to commodity prices when all agricultural emissions are mitigated.[10] This finding is consistent with other modelling done in this area (Golub *et al.* 2013).

Figure 2 Change in New Zealand's RGNDI in 2020 relative to *Baseline* (S-R).



Stroombergen and Reisinger's results for NZ in 2020 are laid out in Figure 2. These results are for the scenarios in Table 1, with global CO2 prices and livestock commodity prices as inputs. *All in this Together* is clearly the best for NZ as a whole, followed by *Agriculture Out* and the *Agricultural Conundrum*. New Zealand's welfare is measured in Real Gross National Disposable Income (RGNDI).[11] As is consistent with current international policy, NZ faces a mitigation target for 2020 that includes agricultural non-CO_2 emissions. Stroombergen and

[10] This surprisingly small livestock price effect from pricing agricultural emissions arises because of an indirect effect: reducing agricultural emissions reduces the CO2 prices needed to meet the target. A lower CO2 price reduces the pressure to avoid deforestation and reforest on land that could be used for extensive livestock and hence lowers livestock prices.

[11] RGNDI measures NZ's income from all sources – domestic and from offshore investments – minus income flowing overseas. Overseas income flows includes the purchase of international emission units if NZ's net emissions exceed the national mitigation target. It also includes any changes in NZ's terms of trade.

Reisinger assume that the government earns money for extra mitigation below the target or has to pay for extra emissions above the target, at the carbon price. This assumption impacts NZ's RGNDI. A target for 2020 emissions of 15% below 1990 levels is assumed for all scenarios, though this target does not include agricultural emissions in *Agriculture Out*. New Zealand's official target for 2020 is 5% below 1990 levels, and it has recently announced an 'Intended Nationally Determined Contribution' of 30% below 2005 emissions by 2030, which is equivalent to net emissions around 11% below 1990 gross emissions by 2020. The reader should not dwell on whether RGNDI increases or decreases and focus instead on comparing the scenarios.[12]

The *Agricultural Conundrum* is least preferred economically for NZ as it places a cost on NZ farmers, and hence the New Zealand economy, to reduce or pay for NZ's agricultural emissions, even though the rest of the world is not reducing or pricing theirs. Individual NZ farmers, and in the medium term NZ producers as a group, are price takers on international markets (Woods with Coleman 2012) and under this scenario face higher CO2 prices and lower livestock commodity prices. The *Agriculture Out* scenario has the same international commodity and CO2 prices as the *Agricultural Conundrum* but is preferable for NZ compared with the *Agricultural Conundrum* as we no longer have to reduce our agricultural emissions for our national mitigation target.[13] However, *All in this Together* is best for NZ given our efficient agricultural sector, as this scenario has higher livestock commodity prices and lower CO2 prices.

2.2. Metrics

Metrics allow the trading off of mitigation of one type of GHG against another in order to mitigate climate change at least cost. However, comparing GHGs is like comparing apples and oranges. They are different fruit, but can be compared quantitatively in a number of ways. Metrics for fruit can focus on total number, weight, length of time they last in a cool store, value at a local market, nutritional content, or a combination. The most effective metric depends on the aim of the comparison. To be most efficient within a climate change context, the metric chosen needs to be the best proxy for the aims of global climate change policy, such as limiting

[12] Recent modelling on a 2025 or 2030 target has been undertaken by Infometrics (2015) and Daigneault (2015). The former uses the same ESSAM Computable General Equilibrium model of the NZ economy as S-R. They show less optimistic results for NZ's RGNDI for comparable mitigation targets for NZ; this difference may be partly due to the treatment of global livestock commodity prices, and partly due to differences in scenarios and assumptions, especially regarding global climate policy and mitigation. Stroombergen and Reisinger use the very detailed GLOBIOM model to determine global livestock commodity price changes.

[13] This result relies on using the same mitigation target of 15% below 1990 level for NZ across the three scenarios. If agricultural emissions were not included in national mitigation targets, it is likely NZ's target would be stronger compared with when agricultural emissions are included in national mitigation targets.

total temperature change or limiting the rate of temperature change (Tol *et al.* 2008). As CO_2 is the main GHG for climate change, metrics usually measure other GHGs relative to CO_2, and S-R look at two options - Global Warming Potential (GWP), and Global Temperature Change Potential (GTP).

Methane is particularly sensitive to the choice of metric, making metrics of considerable interest to NZ. The Global Warming Potential with a time horizon of 100 years (GWP) has been adopted as the standard climate change metric under the UNFCCC (van den Berg *et al.* 2015). However, GWP now assigns methane a value of 28 times CO_2 (IPCC 2013a), whereas GTP assigns methane a value of just 7 times CO_2 over the same 100-year time horizon. In this subsection we explore the reasons behind these differences and the implications for NZ.

2.2.1. GWP

GWP measures the average radiative forcing (warming effect) of the emission of 1kg of a GHG over a 100 year time period relative to the warming effect of the emission of 1kg of CO_2. Radiative forcing is the net increase in solar energy being retained in the Earth's atmosphere relative to pre-industrial conditions. The emission of a GHG increases its concentration in the atmosphere, which increases the radiative forcing, which in turn gradually warms the atmosphere (IPCC 2013b). The GWP measures the cumulative warming effect over a defined time horizon following the emission of a gas, with 100 years being the most widely used time horizon that is also used currently in the UNFCCC and its Kyoto Protocol. The GWP therefore is analogous to measuring the effect of installing extra insulation in a house ceiling. If a heater is turned on in the house, GWP would measure the average amount of heat energy kept in the house by the extra insulation over a specified time period. The GWP value would then compare the effectiveness of different types of insulation (both its effectiveness in insulating a house, and how long the insulation lasts before it decays and becomes less effective). GWP reflects therefore the effectiveness of different types of GHG at retaining heat energy in the atmosphere, due to both their ability to absorb infrared radiation and their lifetime in the atmosphere after they have been emitted, rather than directly measuring the warming caused by the gases.

While GWP is currently measured over a 100 year time period, different GHGs are naturally removed from the atmosphere at different rates (van den Berg *et al.* 2015). CO_2 is a long-lived gas, whereas methane dissipates much more rapidly with a half-life of approximately

12 years. Therefore, choosing a 20 year time period or a 200 year time period instead can create large changes in the exchange rates between CO2 and methane.

Table 2 displays GWP and GTP values over different time periods for methane.

Table 2 Methane emission values for GWP and fixed GTP metrics. They represent how many kilograms of CO2 1kg of methane is worth (S-R).

Metric	20 year	100 year	500 year
GWP	72	25*	8
GTP	50	7	0.7

* These values change based on atmospheric concentrations of the various gases. The figures above are from S-R.

2.2.2. GTP

Global Temperature Change Potential (GTP) is the most prominent alternative to GWP. Essentially it measures the global temperature change in an individual future year due to the emission of a GHG, relative to CO2, rather than the cumulative warming effect over a period of many years. For example, a fixed 100 year GTP measures the predicted temperature change that would occur 100 years from now as a result of an additional kg of a GHG released today, relative to 1kg of CO2. In terms of the house metaphor, where GWP measures the insulation, GTP compares the actual change temperature at a single future point in time. This would be like installing two different types of insulation into identical houses with identical heaters at identical settings, and comparing the temperature change in 100 minutes time.

Given that GTP measures temperature at a single point in time, it values all the damages at that point only (Gillett and Matthews 2010). Like GWP, due to the rapid decay time of methane relative to CO2, the chosen timeframe has a large bearing on the value of methane, as demonstrated in Table 2.

2.2.3. Implications for New Zealand

From a global perspective, the 100 year GWP is the more efficient metric for meeting S-R's 2100 target compared with the 100 year GTP, with GTP adding 5 to 20% to global mitigation costs. It is important to note that this finding may not hold true for different mitigation targets set for different years, and also depends on the optimisation criterion for the model; if society is concerned about the trajectory of emissions as well as the target, the finding could be different.[14] The prices the different metrics create under the three scenarios are summarised in Table 3. Because GTP puts a lower weight on methane emissions compared with GWP, deeper and earlier cuts to global CO2 emissions are needed to compensate for the lower cuts to methane emissions. Therefore, GTP requires a higher global CO2 price in order to meet the mitigation target. However, the lower cost of methane emissions under GTP means the agricultural sector faces lower costs, so global livestock commodity prices rise by less.

Table 3 The effects of the GWP and GTP metrics on the CO2, methane and livestock commodity prices (S-R).

Scenario	Metric	CO2 price/tonne ($NZ)	Methane price/tonne ($NZ)	Livestock commodity price increase over baseline
All in this Together	GWP (25)	$35	$866	18%
	GTP (7)	$42	$295	16%
The Agricultural Conundrum	GWP (25)	$77	$1927	14%
	GTP (7)	$88	$618	14%*
Agriculture Out	GWP (25)	$77	$0 (agriculture)	14%
	GTP (7)	$88	$0 (agriculture)	14%*

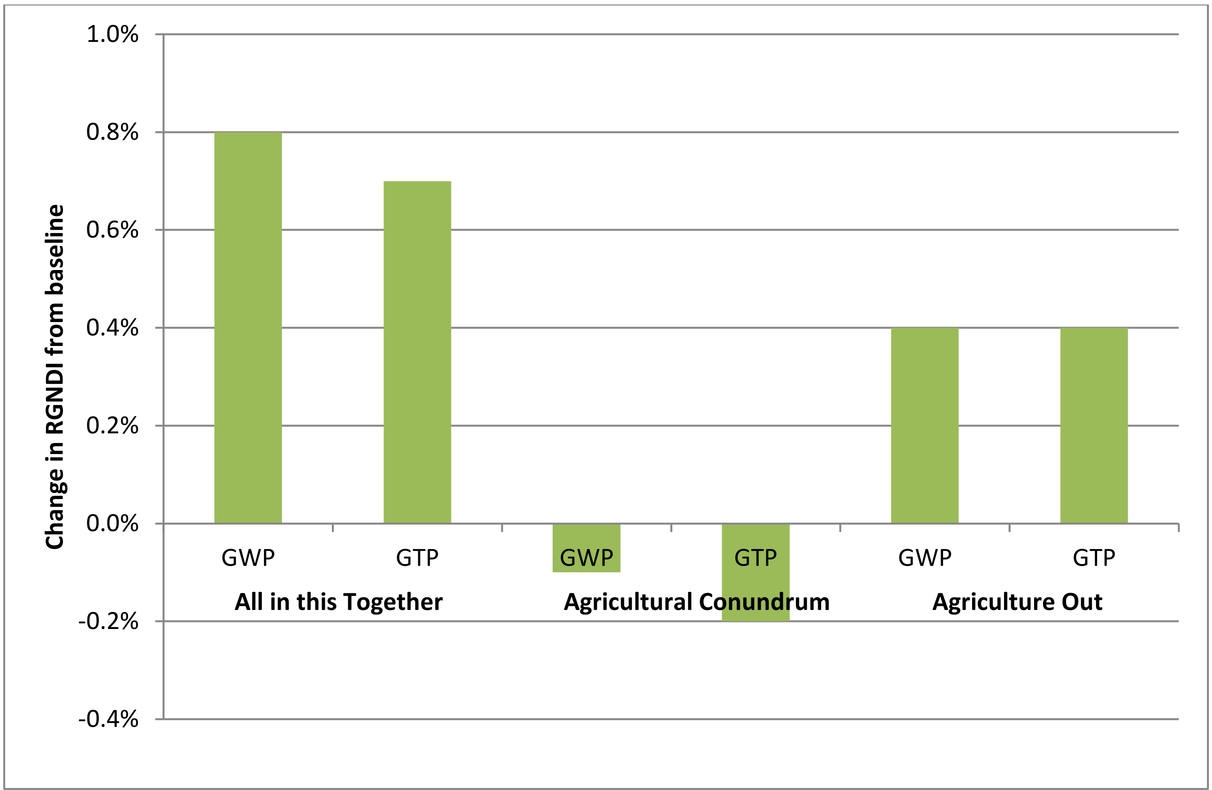
* Stroombergen and Reisinger calculate these livestock commodity prices only using GWP, so they have been assumed to be the same for GTP. The higher CO2 price will increase upward pressure on livestock commodity prices compared with GWP. Given that agricultural non-CO2 emissions are not priced globally under the *Agricultural Conundrum* or *Agriculture Out* scenarios, these livestock commodity prices price would likely be slightly higher for GTP if calculated.

As Figure 3 shows, the choice of metric proves to be a minor issue compared with the overall scenario NZ faces, even though exchange rates between methane and CO2 vary so much. Though the costs of international emission credits for the NZ government are lower overall under GTP, those lower costs are partly cancelled out by the higher CO2 prices and by the lower

[14] Strefler *et al.* (2014) and van den Berg *et al.* (2015) both find that a 100 year GWP does a reasonable job at meeting global mitigation targets cost effectively, and that the main difference between metrics is the trajectory of methane and nitrous oxide emissions over the next century.

livestock commodity prices. Note that GWP always dominates GTP, including in the *Agriculture Out* scenario. In 2020 the change in RGNDI is just 0.03% higher under GWP, but in the results S-R present for 2050, the preference for GWP increases.

Figure 3 Change in NZ's RGNDI in 2020 from *Baseline* under the three scenarios and two metrics considered (S-R).



3. Implications for New Zealand farmers

We now investigate the implications of S-R's results for 2020 for two model NZ farms. In this section we briefly describe the modelling approach and then discuss the impacts of each of the previous scenarios.

3.1. Modelling approach

To compare the economic welfare of NZ with the welfare of NZ farmers, we developed two model farms – one dairy and one sheep and beef. For more details, see Appendix 2. The dairy farm is based on Beukes *et al.*'s (2010) average Waikato dairy farm in the 2006/7 season, and the sheep and beef farm is based on Smeaton *et al.*'s (2011) 2008/09 base Central North

Island Hill Country sheep and beef farm. To smooth out volatility in international commodity prices we use an average of Ministry of Primary Industries (MPI) monitor farm prices for 2002 to 2011. We calculate percentage change in profit from baseline by adjusting the farm balance sheet by the international livestock commodity price index and international GHG prices from Table 3. We assume no increases in production efficiency, no GHG mitigation and no changes in input prices for fertiliser or energy, other than a direct increase by the price of CO2. Thus, these calculations are indicative only. For a study of NZ dairy farms which allows mitigation through efficiency and production changes and uses GWP and GTP metrics, but does not alter output prices, see Reisinger and Ledgard (2013).

3.2. Implications of the scenarios for farmers

This subsection looks at our results for when we put a 10% and 100% liability on the farms' non-CO2 emissions and use the GWP metric. For all scenarios we put a 100% liability on CO2 emissions. We assume that farmers are international and domestic price takers. Thus, they are unable to pass any extra costs on to consumers internationally or domestically, or to workers or agricultural input suppliers. However, they benefit from international commodity price rises associated with global climate policy.

Figure 4 Emission costs per hectare of the dairy and sheep and beef farms as a percentage of baseline profits in 2020, with 10% liability on non-CO2 and 100% liability on CO2 emissions.

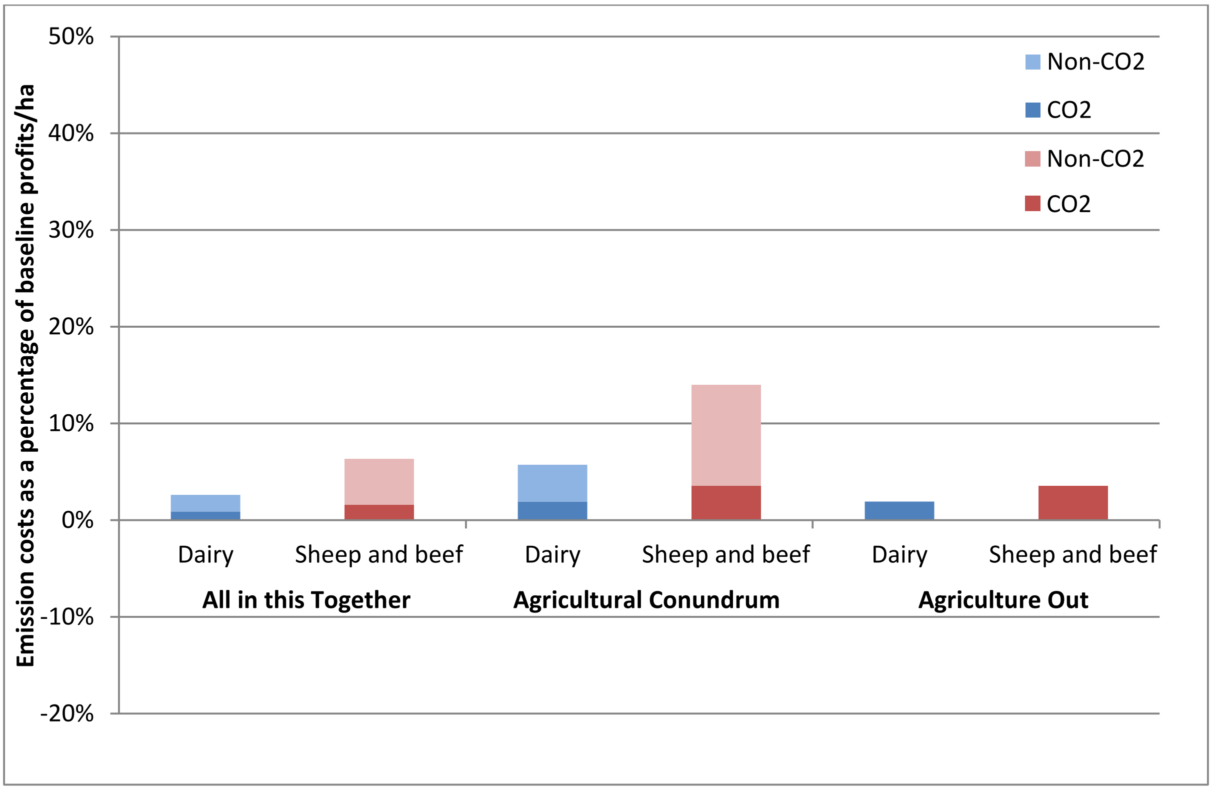


Figure 4 shows the cost to dairy and sheep and beef farmers of their emissions as a percentage of baseline profit, with a 10% liability for non-CO2 emissions. Profits are measured as earnings before interest and tax, and the baseline profits for the dairy farm are $2250 per hectare, and for the sheep-beef farm $271 per hectare, both in 2005 NZ dollars. The sheep and beef farm's emission costs follow a similar pattern, though the figures are roughly double as a percentage of profit. Emission costs are small as a percentage of profit and highest under the *Agricultural Conundrum* as expected, given the higher GHG prices and 10% liability for their non-CO2 emissions. *All in this Together* and *Agriculture Out* have similar emission cost levels as the higher GHG prices in the latter scenario are offset by farmers only having to pay for their CO2 emissions.

Figure 5 Farm change in profit/ha compared with baseline at 10% liability for agricultural emissions in 2020, and S-R's results for New Zealand's change in RGNDI compared with *Baseline.*

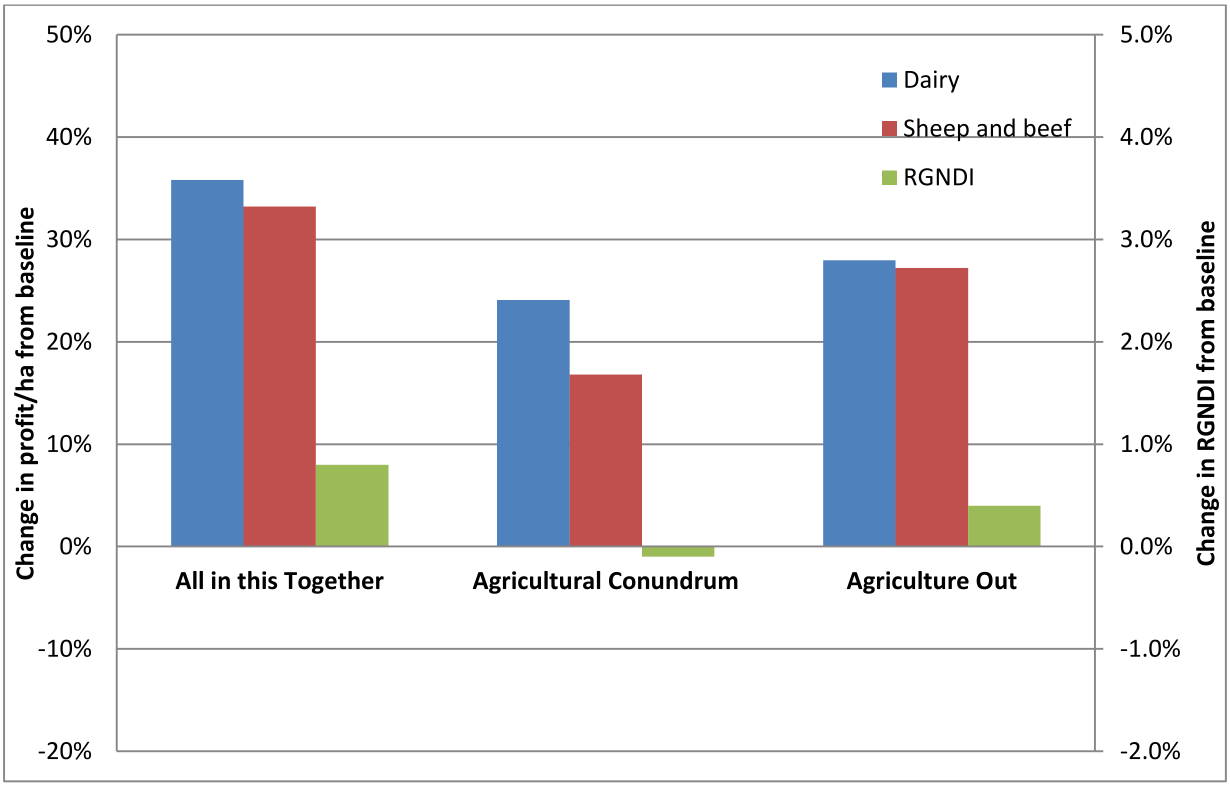
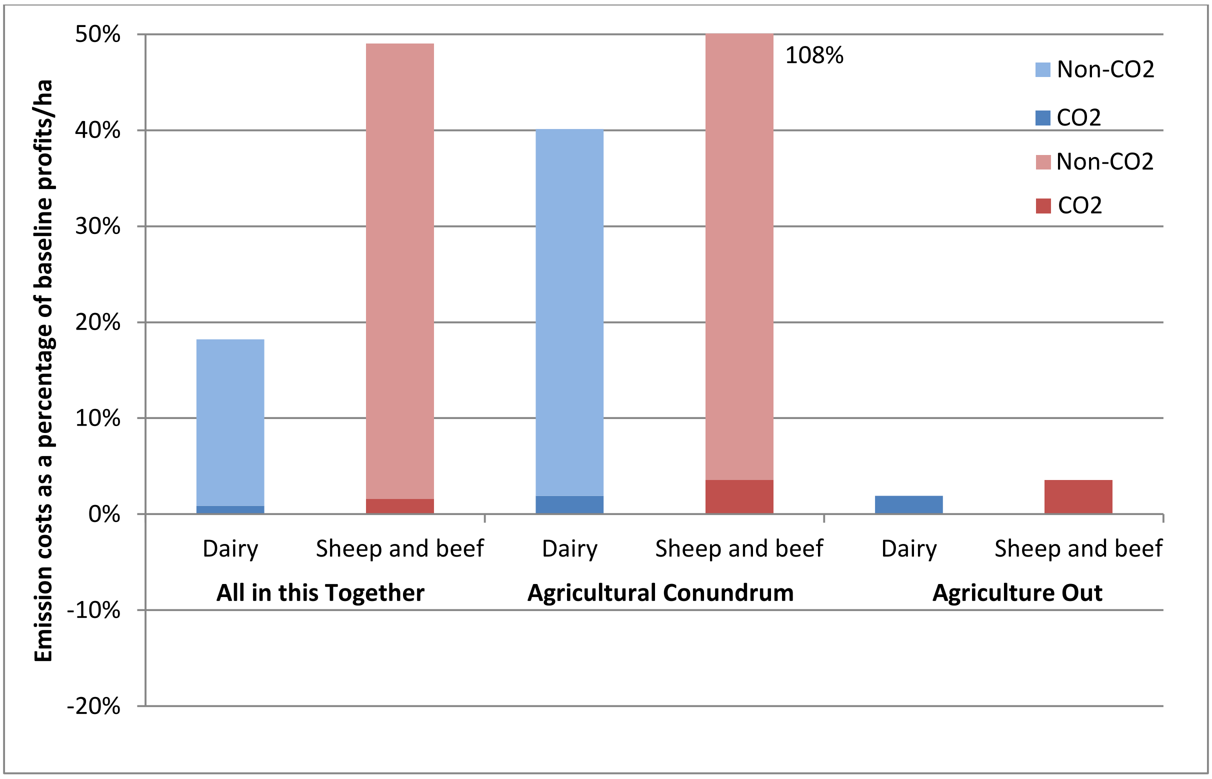


Figure 5 shows the total change in farmers' profits from baseline with a 10% liability for non-CO2 emissions, next to change in NZ's RGNDI relative to baseline (which uses a much smaller scale, right vertical axis). The costs of Figure 4 are more than offset by the 14% higher livestock commodity prices in *Agricultural Conundrum* and *Agriculture Out* and 18% commodity price rise in *All in this Together*, meaning farmers' profits rise significantly under all scenarios. Farmers are sheltered from 90% of the costs of their non-CO2 emissions in the first two scenarios, meaning they prefer *All in this Together* for its higher commodity prices, even over *Agriculture Out*. Thus, the best scenarios for NZ align with the best scenarios for farmers, though the rise in farmers' profits dwarf the small changes in NZ's RGNDI.

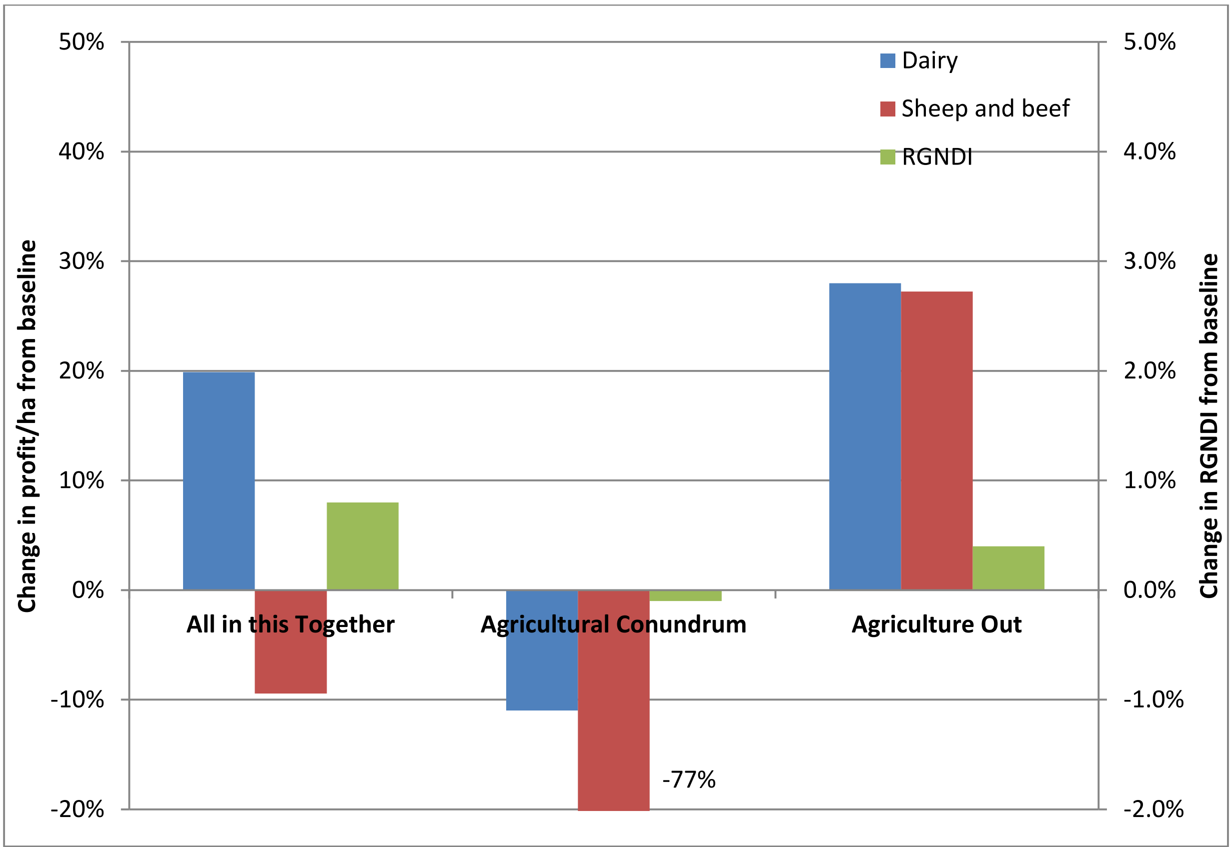
Figure 6 Emission costs per hectare of the dairy and sheep and beef farms as a percentage of baseline profits in 2020, with 100% liability on all emissions.



Emissions costs for farmers increase significantly when they face 100% liability for their non-CO2 emissions, as shown in Figure 6. The higher GHG costs of *Agricultural Conundrum* sees emissions cost dairy farmers 40% of baseline profits, compared with 18% under *All in this Together* and 2% under *Agriculture Out*. Again, sheep and beef costs per hectare take a similar shape to the dairy farm, but notably are 108% of baseline profit in the *Agricultural Conundrum*. Total change in profit relative to baseline now sees *Agriculture Out* most preferred by farmers (Figure 7), given livestock commodity prices remain at the levels from Figure 5. Therefore, with 100% liability, farmers' interests no longer align with NZ's interests. As expected, the *Agricultural Conundrum* is worst for farmers. Dairy profits are relatively robust under all scenarios, whereas sheep and beef profits take a 77% reduction under *Agricultural Conundrum*. The composite livestock commodity price could exaggerate this difference – perhaps global dairy prices would rise less than meat prices; dairy might experience larger losses and sheep and beef smaller.

s

Figure 7 Change in profit/ha compared with baseline of the farms with all emissions at 100% liability in 2020, and S-R's results for NZ's change in RGNDI.



Given the efficiency of NZ's farming, it may seem surprising that they do not prefer *All in this Together*. Stroombergen and Reisinger allow global mitigation of agricultural emissions and we model our farms with no mitigation, which may account for some of this difference. Another contributing factor is that global livestock commodity prices rise 14% without a price on agricultural non-CO2 emissions and only 18% with such a price, so the difference in output prices between scenarios for the farmers is not that large whereas their costs differ markedly.[15]

[15] Another discrepancy between S-R's modelling and our farms is the baseline settings. The GHG prices provided by S-R are in 2005 NZ dollars, as are all the prices in our farm models. However, the livestock commodity prices are in terms of percentage change from baseline, so there are likely to be differences between our baseline prices and S-R's. Our baseline is average farmgate prices from 2002 to 2011, whereas S-R's baseline is business as usual prices in 2020 (excluding any damages from climate change). Therefore, the percentage change in livestock commodity prices from baseline may be different when measured from our baseline, which could impact the relative percentage changes between scenarios. However, S-R's baseline livestock prices in 2020 are only slightly higher than from 2002 to 2011, so the impact on our results should be marginal.

The former price rise is from global land use change driven by a price on CO2 alone; it assumes that land use change is fully responsive to global climate policy. When agriculture is excluded (*Agriculture Out*), the CO2 price required to meet the temperature target rises. This means there is more forest and less agricultural land and hence livestock prices rise further; farmers benefit from this.

From New Zealand's perspective it is also important to note that S-R assume NZ agriculture face a 10% liability in 2015, rising by 1.3% per year. If S-R modelled NZ farmers with 100% liability, their results would likely show a marginally higher RGNDI for NZ under each scenario, except *Agriculture Out*, which has no non-CO2 component. This result would follow because agriculture would face the full price of their emissions, so would mitigate to an efficient level, and therefore reduce the costs to New Zealand of international emission credits.

3.3. Implications of metrics for farmers

We now consider the implications of metrics under the scenarios for farmers. We look only at 100% liability for all emissions as the differences between metrics are negligible for farmers facing a 10% liability on their non-CO2 emissions.

Figure 8 Change in profit/ha compared with baseline of the farms with all emissions at 100% liability in 2020, and S-R's results for NZ's change in RGNDI, using the GWP and GTP metrics.

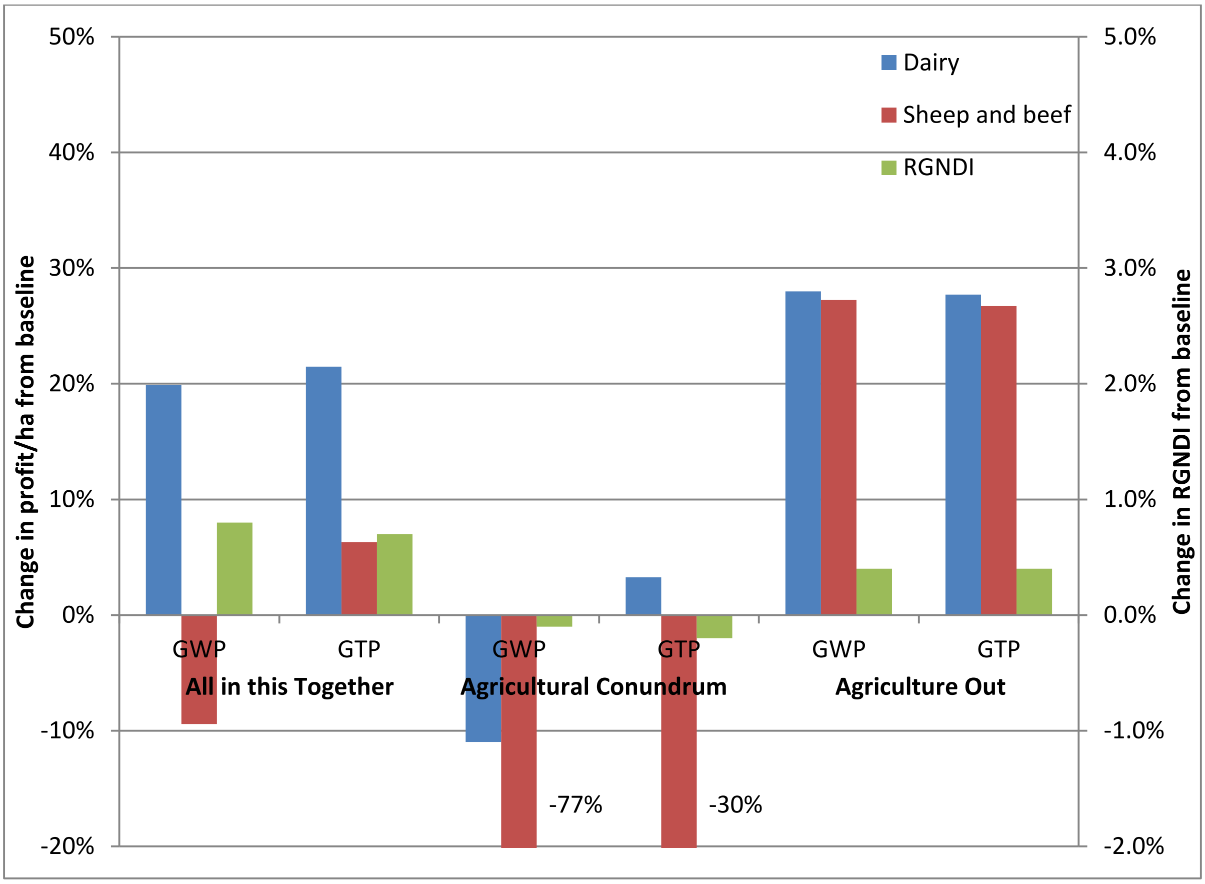


Figure 8 shows the change in profitability compared to baseline for farmers facing 100% liability on their emissions, under the three scenarios and two metrics. In general and for our assumption that there is no mitigation technology available, farmers prefer the GTP metric over GWP. While this metric leads to higher global CO2 prices and lower livestock prices (Table 3), the fact that it puts a weight of 7 on methane relative to CO2, versus 25 under GWP, more than offsets the differences. The differences are especially large under the *Agricultural Conundrum* and larger for sheep and beef farms than dairy farms. There is little difference between metrics under *Agriculture Out*. Therefore, with 100% liability for non-CO2 emissions, the choice of metric is significant for farmers, and farmers prefer GTP over GWP. This is in contrast to the impact on NZ's RGNDI, for which GWP is always preferred. Overall though, which scenario is still more important than which metric is chosen, even for farmers.

4. Conclusion

New Zealand and our farmers have a strong interest in how global agriculture is included in any international agreement on climate change. This study provides some insight into NZ's optimal strategy in international climate change negotiations, and the implications for NZ farmers of three scenarios and the GWP and GTP metrics.

In this paper we discuss the insights provided by S-R. Their results suggest NZ's best strategy in international climate change negotiations is to push for the *All in this Together* scenario, because it leads to lower global GHG prices and higher livestock commodity prices. Regarding the question of metrics, the prominence of methane in NZ's emissions profile *prima facie* suggest a metric that puts a weighting of 7 on methane compared to CO2 (GTP) would be far better for NZ than a weighting of 25 (GWP). However, NZ is economically better off using the GWP metric under S-R's scenarios as it is more suited to the global mitigation target that they consider and the global efficiency gains also lead to gains for New Zealand. In any case, the choice of metric is much less important for NZ than whether global agricultural GHGs are mitigated or not, and whether CO2 is mitigated globally – particularly mitigation through reforestation and reduced deforestation.

We have extended S-R's modelling by considering the impact of their scenarios on farm profits, as farmers' interests may not align with national interests. How farm profits are affected by the three scenarios depends critically on the level of liability they face for their emissions. When facing a 10% liability on their non-CO2 emissions, farmers prefer *All in this Together*, given it has the highest livestock commodity prices and emission costs are small as a percentage of profit under all three scenarios. Our modelling shows that with 100% liability for emissions farmers prefer *Agriculture Out*, though *All in this Together* is not too far behind. This finding may seem surprising. Given that NZ farmers are very efficient producers, they benefit from their competitors having to face costs for their agricultural emissions and it seems that they should favour *All in this Together*, as does NZ as a whole. However, including agricultural emissions reduces the CO2 price significantly and this lowers livestock prices because more agricultural land is available globally; there is less competition from forests. Also, Stroombergen and Reisinger's models allow for global and NZ mitigation of agricultural non-CO2 emissions, including through land use change, whereas we assume no mitigation and no land use change on our farms. By allowing global mitigation, the livestock commodity prices rise by less than they would without allowing mitigation. Overall, the fact that our modelling shows little difference between *All in this Together* and *Agriculture Out* for farmers is a striking result in itself given the difference in emission costs faced by farmers between the two scenarios.

As expected our results show that (like NZ as a whole) farmers also want to avoid the *Agricultural Conundrum.* Outside of that scenario, our modelling suggests farmers have a preference for the GTP metric over the GWP if no mitigation technology is available, but the difference is not as large as the difference between overall scenarios. The preference for GTP over GWP by NZ farmers is echoed by Reisinger and Ledgard (2013).

Global climate policy to date has seen agricultural emissions included in national mitigation targets, but no countries have done much to mitigate agricultural emissions. Current global climate policy puts us close to the *Agricultural Conundrum* scenario in 2020, though without sufficient pledges to reach a 2°C limit to global warming.[16] However, we might expect countries to take at least some mitigation actions within their agricultural sectors. Cooper *et al.* (2013) provide a useful summary of current domestic agriculture climate policy in a range of countries – including information provision and subsidies, but not pricing emissions directly. Given the global importance of agricultural emissions, it seems unlikely we will ever end up in the *Agriculture Out* scenario, so NZ should be pushing for other countries to include agricultural emissions in their national climate policies. While the *All in this Together* scenario is not going to happen by 2020, and we are unlikely to be near it even by 2030, the closer to it we get, the better for NZ. To ever achieve *All in this Together,* significant barriers on an international level must be overcome, including barriers to GHG prices flowing through to land use and agricultural sectors in every country. Nevertheless, NZ's negotiating position will be much stronger if we are seen to be taking action to reduce our agricultural emissions, through policy and research. To date NZ has conducted a significant amount of research in this area (Cooper *et al.* 2013), including establishing the Global Research Alliance on Agricultural GHGs.[17]

NZ should continue to consider how other countries are treating their domestic agriculture when negotiating our national mitigation target, and when setting the level of emissions liability for our agricultural sector. The ability of NZ's agricultural sector to mitigate and bear some of the costs of their GHGs is important if agricultural emissions continue to be included in our national mitigation targets, especially if the NZ government must buy international carbon units to offset our agricultural emissions. Recent dairy prices illustrate that farmers do face volatile international commodity prices and our modelling suggests that farmers

[16] The current (July 2015) mid-point estimates by climateactiontracker.org/ of global mitigation pledges is 3.1°C.
[17] http://www.globalresearchalliance.org/about-us/. Accessed August 2015.

may see much larger gains or losses from international climate policy than the country as a whole. Government must therefore be mindful of these factors when deciding how large an emissions liability individual farms can bear.

Including agricultural emissions in global climate change policy, both through increasing the mitigation potential for agriculture and ensuring that available mitigation potential is realised on farms, is likely to be the lowest cost way for the world to reach our climate change mitigation ambitions and it should also be best for NZ. If the world moves towards efficiently mitigating agricultural emissions, NZ could focus on continuing to be among the most efficient livestock producers in the world. We are also well placed to innovate on domestic agriculture policy and help other livestock farmers become more efficient too (Cooper *et al.* 2013; NZAGRC 2015). After all, when it comes to climate change, we are all in this together.

5. References

Adler, A. A., G. J. Doole, A. J. Romera and P. C. Beukes. 2013. "Cost-Effective Mitigation of Greenhouse Gas Emissions from Different Dairy Systems in the Waikato region of New Zealand." *Journal of Environmental Management*, 131: 33–43.

Anastasiadis, S. and S. Kerr. 2013. "Mitigation and Heterogeneity in Management Practices on New Zealand Dairy Farms." *Motu Working Paper* 13-11. Wellington: Motu Economic and Public Policy Research. http://motu-www.motu.org.nz/wpapers/13_11.pdf

Ballingal, J., C. Schilling and A. Stroombergen. 2011. "Macroeconomic impacts of the New Zealand Emissions Trading Scheme: A Computable General Equilibrium analysis." Wellington: Prepared for Ministry for the Environment by NZIER and Infometrics. https://www.climatechange.govt.nz/emissions-trading-scheme/ets-review-2011/supporting-info/macro-economic-impacts-of-the-nzets.pdf

Beukes, P. C., P. Gregorini, A. J. Romera, G. Levy, and G. C. Waghorn. 2010. "Improving Production Efficiency as a Strategy to Mitigate Greenhouse Gas Emissions on Pastoral Dairy Farms in New Zealand." *Agriculture, Ecosystems & Environment* 136(3-4): 358–365.

Clark, H., F. Kelliher and C. Pinares-Patino. 2011. "Reducing CH4 Emissions from Grazing Ruminants in New Zealand: Challenges and opportunities." *Asian-Australian Journal of Animal Science* 24(2): 295–302.

Cooper, M. H., J. Boston and J. Bright. 2013. "Policy Challenges for Livestock Emissions Abatement: Lessons from New Zealand." *Climate Policy* 13(1): 110-133.

Daigneault, A. 2015. "Modelling the Economic Impact of New Zealand's post-2020 Climate Change Contribution." Auckland: Prepared for the Ministry for Primary Industries and the Ministry for the Environment by Landcare Research. https://mfe.govt.nz/sites/default/files/media/Extra%20downloads/Source%20file/economic%20impact%20of%20NZ%20post-2020%20climate%20change%20contribution.docx

Eckard, R. J., C. Grainger, and C. A. M. de Klein. 2010. "Options for the Abatement of Methane and Nitrous Oxide from Ruminant Production: A review." *Livestock Science* 130(1-3): 47–56.

ETS Review Panel. 2011. "Doing New Zealand's Fair Share. Emissions Trading Scheme Review 2011: Final report." Wellington: Ministry for the Environment. http://www.climatechange.govt.nz/emissions-trading-scheme/ets-review-2011/

Gernaat, D. E. H. J., K. Calvin, P. L. Lucas, G. Luderer, S. A. C. Otto, S. Rao, J. Strefler, D. P. van Vuuren. 2015. "Understanding the Contribution of Non-Carbon Dioxide Gases in Deep Mitigation Scenarios." *Global Environmental Change* 33: 142-153.

Gillett, Nathan P. and H. D. Matthews. 2010. "Accounting for Carbon Cycle Feedbacks in a Comparison of the Global Warming Effects of Greenhouse Gases," *Environmental Research Letters* 5(3): 1-6.

Golub, A. A., B. B. Henderson, T. W. Hertel, P. J. Gerber, S. K. Rose and B. Sohngen. 2013. "Global Climate Policy Impacts on Livestock, Land Use, Livelihoods and Food Security." *Proceedings of the National Academy of Sciences* 110(52): 20894-20899.

Infometrics. 2015. "A General Equilibrium Analysis of Options for New Zealand's post-202- Climate Change Contribution." Wellington: Prepared for Ministry for the Environment by Infometrics. http://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/general-equilibrium-analysis_0.pdf

IPCC. 2013a. "Chapter 8: Anthropogenic and Natural Radiative Forcing." In T. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. Allen, J. Boschung, … P. Midgley (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdon and New York, NJ, USA: Cambridge University Press.

IPCC. 2013b. "Summary for Policymakers." In T. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. Allen, J. Boschung, … P. Midgley (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdon and New York, NJ, USA: Cambridge University Press.

IPCC. 2014. "Chapter 11: Agriculture, forestry and other land use (AFOLU)." In O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, … J. C. Minx (Eds.), *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 811–922). Cambridge, United Kingdon and New York, NJ, USA: Cambridge University Press.

Kerr, S. and W. Zhang. 2009. "Allocation of New Zealand Units within Agriculture in the New Zealand Emissions Trading System." *Motu Working Paper* 09-16. Wellington: Motu Economic and Public Policy Research.

Lennox, J. A. and R. van Nieuwkoop. 2010. "Output-based Allocations and Revenue Recycling: Implications for the New Zealand Emissions Trading Scheme." *Energy Policy* 38(12): 7861–7872.

New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC). 2015. "What we are Doing." Fact sheet, April 2015. http://www.nzagrc.org.nz/fact-sheets,listing,177,what-we-are-doing.html

Reisinger, A., P. Havlik, K. Riahi, O. van Vliet, M. Obersteiner and M. Herrero. 2013. "Implications of alternative metrics for global mitigation costs and greenhouse gas emissions from agriculture." *Climatic Change* 117(4): 677-690.

Reisinger, A. and S. Ledgard. 2013. "Impact of greenhouse gas metrics on the quantification of agricultural emissions and farm-scale mitigation strategies: a New Zealand case study." *Environmental Research Letters* 8(2): 1-8.

Reisinger, A., J. Rogelj, and A. Daigneault. 2015. "Interactions Between Agriculture Non-CO2 Mitigation Choices and Fossil CO2 Emissions within Integrated Low-Carbon Pathways." Poster presented to "Our Common Future under Climate Change" conference, Paris, July 2015.

Reisinger, A. and A. Stroombergen. 2011. "Implications of Alternative Metrics to Account for Non-CO2 GHG Emissions." Report prepared for Ministry of Agriculture and Forestry by AgResearch and Infometrics.

Smeaton, D. C., T. Cox, S. Kerr, and R. Dynes. 2011. "Relationship Between Farm Productivity, Profitability, N Leaching and GHG Emissions: A modelling approach." *Proceedings of the New Zealand Grassland Association*, 73: 57–62.

Strefler, J., G. Luderer, T. Aboumahboub and E. Kriegler. 2014. "Economic Impacts of Alternative Greenhouse Gas Emission Metrics: A model-based assessment." *Climatic Change* 125: 319-331.

Stroombergen, A. and A. Reisinger. 2012. "The Macroeconomic Impact on New Zealand of Alternative GHG Exchange Rate Metrics." Paper presented to EcoMod Conference, Seville, July 2012. http://ecomod.net/system/files/GHGmetrics.pdf

Tol, R. S., T. K. Berntsen, B. C. O'Neill, J. S. Fuglestvedt, K. P. Shine, Y. Balkanski and L. Makra. 2008. "Metrics for aggregating the climate effect of different emissions: a unifying framework." *ESRI Working paper*. http://www.econstor.eu/handle/10419/50162

Van den Berg, M., A. F. Hof, J. van Vliet and D. P. van Vuuren. 2015. "Impact of the choice of emission metric on greenhouse gas abatement and costs." *Environmental Research Letters*, 10(2).

Van Vuuren, D. P., J. Weyant and F. de la Chesnaye. 2006. "Multi-gas scenarios to stabilize radiative forcing." *Energy Economics* 28(1): 102–120.

Woods, D. with A. Coleman. 2012. "Price, Quality, and International Agricultural Trade." *Motu Working Paper* 12-08. Wellington: Motu Economic and Public Policy Research.

6. Appendix 1 - Stroombergen and Reisinger's modelling approach

A number of models were used in S-R's study. More detailed descriptions are provided in S-R; a brief description of their modelling approach is provided here.

First, the global climate model MAGICC version 6 is used to estimate the values for methane and nitrous oxide using the metrics GWP and fixed GTP. These metrics are then used to estimate the lowest cost paths for the mitigation of GHGs to reach the 450ppm global target under the various scenarios using the global economic model MESSAGE. MESSAGE determines the prices for CO2, methane and nitrous oxide emissions which ensure the 450ppm target is achieved at lowest cost.

The effects of these different emission prices on global agriculture are then modelled by GLOBIOM. GLOBIOM models world agriculture demand and supply in much more detail than MESSAGE. Stroombergen and Reisinger use it to produce a livestock commodity price index to reflect changes in global meat and milk prices, and a horticultural commodity price index to reflect changes in crop-based global food prices. We use the composite livestock commodity price index as S-R conclude that this is the most robust output from GLOBIOM. GLOBIOM projects under the three scenarios that bovine meat price would rise by the lowest amount, followed by milk prices (all sources), with sheep and goat meat prices rising by the most, demonstrating that specific sectors are likely to see different magnitudes of price changes. Therefore, the results for the profitability of our model farms will not reflect the global realities in their sectors, however the livestock commodity price index is the best indication of price changes we have for this study.

Finally, the metrics from MAGICC, the global carbon prices from MESSAGE and the commodity prices from GLOBIOM are fed into a multi-sector model of the NZ economy, ESSAM. ESSAM is then used to compare the NZ economy under the scenarios described above, against the baseline scenario of no mitigation of climate change for the years 2020 and 2050.

6.1. ESSAM assumptions in more detail

Stroombergen and Reisinger assume NZ's 2020 national mitigation target is net emissions 15% below 1990 gross emissions. They assume forestry will absorb 16.1Mt of CO2 in 2020 regardless of the scenario, thereby reducing NZ's international emissions liability. The actual level of forestry sequestration will depend on accounting rules in the international agreement, as well as the carbon price, to which it is very difficult to predict how foresters will respond (Ballingal *et al.* 2011). Therefore, comparison between scenarios is done with no change in NZ's forestry levels; this is unlikely to be the case given the change in GHG prices, but allows comparisons to be made between scenarios without adding in inaccurate forestry predictions. Stroombergen and Reisinger also assume that liability for various sectors in NZ under the NZETS is as originally proposed, including a 10% obligation for agricultural GHGs in 2015, which is gradually increased by 1.3% per year. The prices in the NZETS are assumed to be set by global emission prices, in 2005 US dollars, with a fixed exchange rate of US$0.70=NZ$1.

In the ESSAM model of the NZ economy, S-R include the ability to mitigate nitrous oxide emissions per unit of agricultural output. However, methane emissions are directly linked to output and they do not include the potential for efficiency improvements in methane. The only way methane mitigation is achieved is through a reduction in output. There are options for the mitigation of methane, evidenced by considerable heterogeneity in the methane per unit of output amongst farms (Anastasiadis and Kerr 2013). However, there is no credible evidence on the cost of methane mitigation or equivalently, GHG price responsiveness.

7. Appendix 2 - Description of farm models used

The emissions data for both farms are calculated by the computer model OVERSEER. Currently agricultural emissions are reported on at the producer level.[18] However, the ETS Review Panel (2011) recommended emissions be calculated on each farm if they were to be captured by the ETS at some future date, suggesting OVERSEER could be used to calculate every individual farms' emissions. Therefore, it is possible that the farm models used here will mimic how farms are included in the NZETS in future, though OVERSEER is continually being enhanced in order to be able to model farm emissions more accurately for every possible NZ farm.

All prices are in 2005 NZ dollars, including prices from S-R. Prices calculated by us are adjusted for inflation using the Consumer Price Index.

7.1. Dairy farm

The model dairy farm presented here is based on Beukes *et al.*'s (2010) average Waikato dairy farm. More information about their model can be obtained from their paper; important details are given here.

The farm is based on data from the DairyBase database, which Beukes *et al.* (2010) use to produce a scaled-down, 25ha farm. It is based on averaging farms which used less than 10% imported feed for the 2006/7 season. We based our farm off their baseline, *Farm A*, which had a stocking rate of 3.0 cows/ha and applied 180kg of nitrogen fertiliser per hectare. This baseline farm, and its associated methane and nitrous oxide emissions provided by Beukes *et al.*'s (2010) OVERSEER estimates, is used under all scenarios. They provide data on other emissions including operating emissions from energy use, cultivation, lime and capital items, which we assume to fully consist of CO2 emissions. No mitigation actions are applied.

We report economic profits per hectare, or earnings before interest and tax. These profit figures exclude any interest and rent payments, meaning they provide a good indication of long run profitability once investments in land are paid off, or alternatively, the productive value of the land (Kerr and Zhang 2009). Operating costs and milk production per hectare are estimated using Beukes *et al.*'s (2010) figures, while we estimate milk prices using a ten year average of MPI's Waikato monitor farm $/kg of milk solids for 2002 to 2011.

[18] https://www.climatechange.govt.nz/emissions-trading-scheme/participating/agriculture/obligations/. Accessed August 2015.

7.2. Sheep and beef farm

Our sheep and beef farm model is based on Smeaton *et al.*'s (2011) base Central North Island Hill Country sheep and beef farm. Their farm is based on the 2008/09 MAF Central North Island Hill Country farm, though their farm has a higher stocking rate. It is a 635ha farm with 9.8 stock units per hectare, about a third of which is beef. Emissions per hectare are estimated by OVERSEER; we utilise detailed data provided by Duncan Smeaton. These emissions are broken into methane, nitrous oxide, and a minor extra component, which we assume are CO2 emissions. Again, no mitigation actions are applied to the farm model.

As with the dairy farm, we use economic profits per hectare. We estimate them using MPI Central North Island Hill Country monitor farm data averages for 2002 to 2011. Data for costs and revenues are both estimated using the MPI monitor farm data on operating costs per stock unit and revenue per stock unit.

As for the dairy farm, profits are adjusted from baseline using the livestock commodity price index, metrics and emissions prices from S-R. All revenue per hectare is adjusted by the livestock commodity price index, including the small component from wool, as this is our only price change projection data.[19]

7.3. Robustness of farm models

As a point of comparison, Kerr and Zhang's (2009) numbers for the average profit per hectare of comparable farms are provided, both before and after a $25 emissions charge. These figures are presented for our farm models also, both modelled with no change in farm revenue.

Figures for the average Waikato dairy farm and the national average dairy farm are provided in Table 4. The discrepancies between profit figures can at least in part be explained by higher milk prices over the last few years, outside of the eight-year average pricing used by Kerr and Zhang (2009). Accounting for this difference, the figures line up even more closely.

Kerr and Zhang's (2009) numbers for the average profit per hectare of a similar Central North Island Hill Country sheep and beef farm are provided in Table 5. As with the dairy farm, recent high prices lead to higher profit figures compared with Kerr and Zhang (2009). Again, the difference between our figures and their figures are not large, so we are confident our model sheep and beef farm is an adequate illustration of an average farm.

[19] Wool revenue makes up 13% of total revenue per Stock Unit in our data.

Table 4 A comparison of baseline profits of our Waikato dairy farm with averages estimated by Kerr and Zhang (2009).[20]

Farm	Profit/ha before emissions charge (2005$)	Profit/ha after $25 emissions charge (2005$)	Drop in profit/ha (2005$)	Drop in profit (%)
Average Waikato dairy (Kerr and Zhang, 2009)	$1734	$1460	$274	16%
Average national dairy (Kerr and Zhang, 2009)	$1880	$1605	$275	15%
Our Waikato farm	$2250	$1977	$273	12%

Table 5 A comparison of baseline profits of our Central North Island High Country farm with average profit per hectare of comparable Central North Island Hill Country farms, estimated by Kerr and Zhang (2009).

Farm	Profit/ha before emissions charge (2005$)	Profit/ha after $25 emissions charge (2005$)	Drop in profit/ha (2005$)	Drop in profit (%)
Average hard Central North Island Hill Country (Kerr and Zhang, 2009)	$249	$168	$81	33%
Our Central North Island Hill Country farm	$271	$187	$84	31%

7.4. Drivers and robustness of the results

Two main inputs into our model farms determine their change in profit – global GHG prices and livestock commodity prices. In S-R's international models, the treatment of agricultural emissions (and metric used) determines the price of GHGs, which together determine the change in the livestock commodity price index. These factors in turn are determined by the models' assumptions, and how well the two models that determine these outputs (MESSAGE and GLOBIOM) fit together. The global possibilities for mitigation and

[20] This table and the next use the GWP metric currently used under Kyoto, where methane has a weight of 21, and nitrous oxide has a weight of 310.

their costs determine the GHG prices. Furthermore, the extent to which global GHG prices and livestock prices affect each other will ultimately determine the results for our farm models. Therefore, our results are highly dependent on the assumptions in S-R's models. The livestock price rise is the same for dairy as sheep/beef which is unlikely in reality, but provides a reasonable ballpark estimate of the impact on commodity prices from global climate change mitigation policies in order to compare scenarios.

Recent Motu Working Papers

All papers in the Motu Working Paper Series are available on our website www.motu.org.nz, or by contacting us on info@motu.org.nz or +64 4 939 4250.

15-10 Grimes, Arthur and Marc Reinhardt. 2015. "Relative Income and Subjective Wellbeing: Intra-national and Inter-national Comparisons by Settlement and Country Type"

15-09 Grimes, Arthur and Sean Hyland. 2015. "A New Cross-Country Measure of Material Wellbeing and Inequality: Methodology, Construction and Results."

15-08 Jaffe, Adam and Trinh Le. 2015. "The impact of R&D subsidy of innovation: a study of New Zealand firms."

15-07 Duhon, Madeline, Hugh McDonald and Suzi Kerr. 2015 "Nitrogen Trading in Lake Taupo: An Analysis and Evaluation of an Innovative Water Management Policy.

15-06 Allan, Corey, Suzi Kerr and Campbell Will. 2015. "Are we turning a brighter shade of green? The relationship between household characteristics and greenhouse gas emissions from consumption in New Zealand" (forthcoming)

15-05 Fabling, Richard and Lynda Sanderson. 2015. "Exchange rate fluctuations and the margins of exports"

15-04 Fabling, Richard, Richard Kneller and Lynda Sanderson. 2015. "The impact of tax changes on the short-run investment behaviour of New Zealand firms"

15-03 Sin, Isabelle, Steven Stillman. 2015. "Economic Liberalisation and the Mobility of Minority Groups: Evidence for Māori in New Zealand"

15-02 Grimes, Arthur, Ian Mitchell. 2015. "Impacts of Planning Rules, Regulations, Uncertainty and Delay on Residential Property Development"

15-01 De Rassenfosse, Gaétan, and Adam B. Jaffe. 2015. "Are Patent Fees Effective at Weeding Out Low-Quality Patents?"

14-15 Sin, Isabelle, Richard Fabling, Adam Jaffe, David C. Maré and Lynda Sanderson. 2014. "Exporting, Innovation and the Role of Immigrants."

14-14 McLeod, Keith, Richard Fabling and David C. Maré. 2014. "Hiring New Ideas: International Migration and Firm Innovation in New Zealand."

14-13 Timar, Levente, Arthur Grimes and Richard Fabling. 2014. "That Sinking Feeling: The Changing Price of Disaster Risk Following an Earthquake."

14-12 Dorner, Zack, with Dean Hyslop. 2014. "Modelling Changing Rural Land Use in New Zealand 1997 to 2008 Using a Multinomial Logit Approach."

14-11 Grimes, Arthur, Eyal Apatov, Larissa Lutchman and Anna Robinson. 2014. "Infrastructure's Long-Lived Impact on Urban Development: Theory and Empirics."

14-10 Maré, David C., Lynda Sanderson and Richard Fabling. 2014. "Earnings and Employment in Foreign-owned Firms."

14-09 Kerr, Suzi, and Vicki Duscha. 2014. "Going to the Source: Using an Upstream Point of Regulation for Energy in a National Chinese Emissions Trading System."

14-08 Fabling, Richard, Arthur Grimes and Levente Timar. 2014. "Natural Selection: Firm Performance Following the Canterbury Earthquakes."

14-07 Anastasiadis, Simon, Suzi Kerr, Wei Zhang, Corey Allan and William Power. 2014. "Land Use in Rural New Zealand: Spatial Land Use, Land-use Change, and Model Validation."