Land-use Intensity and Greenhouse Gas Emissions

DRAFT

This documentation paper is currently preliminary and incomplete

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Motu Working Paper ##-##
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Abstract

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Contents

1. Introduction

This short document describes the development of the new Land-use Intensity and Greenhouse Gas Emissions modules of the Land Use in Rural New Zealand (LURNZ) model. The previous versions of these modules yielded outputs that were, within each land use, geographically homogenous over all of New Zealand (Hendy & Kerr, 2006; Hendy & Kerr, 2005), and the main reason for undertaking this work was to introduce spatial heterogeneity into LURNZ's projections of net emissions. The updated intensity and emissions modules enable us to analyse the regional environmental and socio-economic impacts of agricultural emissions trading policy.

Similar to the algorithms documented in Hendy and Kerr (2005, 2006) the functions used in the new LURNZ modules are based on extrapolating historical trends in production activities and in the greenhouse gas (GHG) emissions associated with a unit of activity. In reality, some of these activities (for example, fertiliser use) represent choice variables to the farmer. We acknowledge this fact, but ignore it for the sake of simplicity: the functions we employ depend on time only, and do not account for any behavioural response to a policy option; their purpose is merely to provide a crude tool for calculating the approximate GHG emission implications of rural land use decisions. While this is a conceptually important limitation, we do not expect it to reverse the findings of the simple model.

While based on the same simple principles, this paper departs from previous work in a few important ways. First, as already noted, its results are spatially heterogeneous within land use types. Second, the production activities to which the trends are fitted have been chosen to enable the use of more robust data. Third, the trends are unconstrained: they are not forced through the last observation as they are in Hendy and Kerr (2005, 2006). Fourth, the estimated trends are based on a more flexible logarithmic function.

2. Background

Our primary goal is to introduce spatial heterogeneity into measures of agricultural greenhouse-gas emissions per hectare. The basic strategy we employ to achieve this goal is to use the highly aggregated emissions information form the National Inventory, and combine it with data on regional production to approximate the share of total emissions attributable to different regions of the country. The following (somewhat simplified) example illustrates the process. The National Inventory contains data on the dairy sector from which average emissions per litre of milk produced can be calculated. We assume emissions per litre of milk are constant across regions (plausibly due to similar production technologies), and multiply this national average by region-specific data on litres of milk produced per hectare. This yields a measure of dairy emissions per hectare with regional variability.

The Inventory is updated each year, and the historical data show that emissions associated with producing a litre of milk have, for the most part, been falling over time. Likewise, the data suggest that productivity (milk produced per hectare) has been increasing in most regions of the country. We expect these trends to continue, so when we calculate future values of emissions per hectare, we use productivity and per unit product emission figures that are based on extrapolations of the historical trends. Like in Hendy and Kerr (2005, 2006), these extrapolations are naive in the sense that they are performed by fitting an exogenous trend line to the data points.

3. Dairy farming

We calculate carbon dioxide-equivalent (CO2e) GHG emissions per hectare of dairy land at location *i* and time period *t*, E_{it}^{d}, as the sum of livestock- and fertiliser-related emissions:

$$E_{it}^{d} = IEF_{t}^{d}\frac{1}{m_t}MS_{it} + IEF^{f}f_{t}^{d}$$

Each variable on the right hand side of the equation is described in more detail below, while table 1 provides an overview. Table 2 at the end of this section contains the parameter estimates for the functions we use to project these variables forward in time.

Table 1. Dairy emissions

Variable	Description	Unit of measurement
IEF_{t}^{d}	Implied emission factor for milk	kg CO2e/litre
m_t	Milksolid content	kg milksolids/litre
MS_{it}	Dairy productivity	kg milksolids/ha
IEF^{f}	Implied emission factor for fertiliser	kg CO2e/kg N
f_{t}^{d}	Dairy fertiliser intensity	kg N/ha

3.1. Implied emission factor for milk

The term IEF_{t}^{d} represents the implied emission factor (IEF) for milk production, and captures all dairy livestock-related emissions. It is measured in kilograms of CO2e emissions per litre of milk produced, and is a composite term calculated from data found in the National Inventory. It includes four components: dairy cattle methane (CH4) emissions from enteric fermentation and from manure management, as well as dairy cattle nitrous oxide (N2O) emissions from nitrogen excreted onto agricultural soils and from manure management. To convert methane and nitrous oxide emissions into carbon dioxide-equivalent emissions, we use the global warming potentials (GWP) from the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC).

Each component of the IEF is calculated in a manner that is consistent with the formulas used in the inventory. For example, nitrous oxide emissions from agricultural soils include direct emissions from the nitrogen in urine and dung deposited onto the soil. Not all N2O emissions occur directly: some of the nitrogen in manure volatises, and some of it leaches into the ground before it oxidises. Therefore the component of the IEF that represents N2O emissions from agricultural soils also includes indirect emissions through atmospheric deposition and leaching. The appropriate emission factors for each of these processes and average annual milk yield data are recorded in the inventory. Dairy cattle methane emissions from enteric fermentation and methane and nitrous oxide emissions from manure management are derived analogously.

Figure 1 depicts historical values of emissions per litre of milk calculated from the inventory along with the trend line fitted to the series.[1] Livestock-related emissions associated with milk production have fallen from 0.84 to 0.70 kg CO2e emissions per litre – by about 17 percent – in about two decades due to improvements in animal productivity. (The trend occurs despite the fact that emissions per dairy cattle have been rising – the increase in milk yield per animal offsets this trend).

Figure 1. Dairy livestock emissions per litre of milk produced

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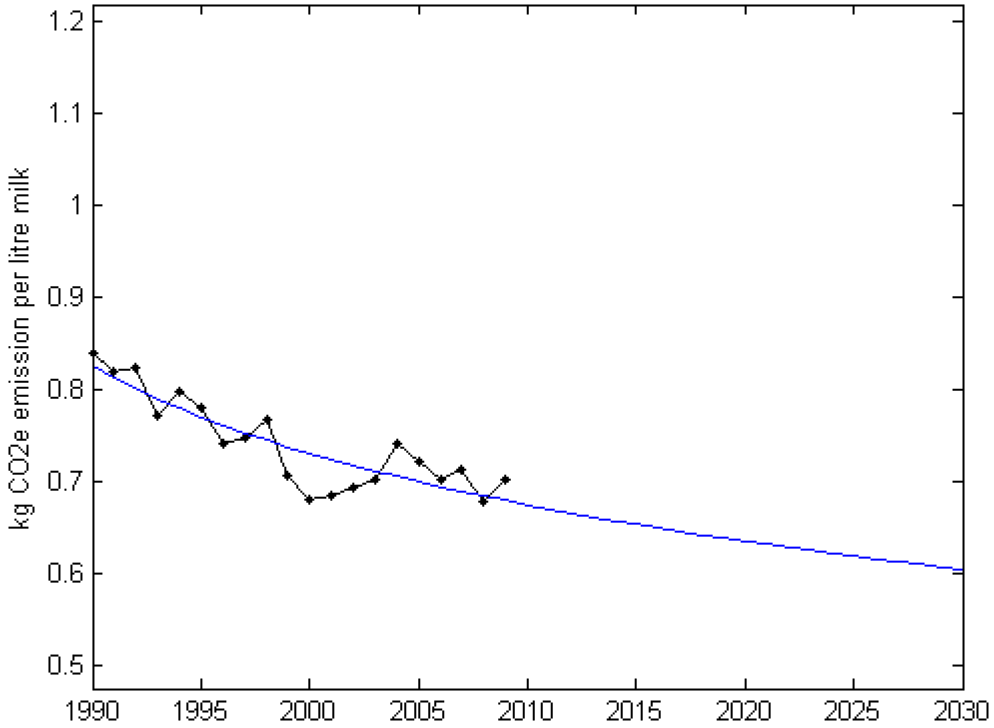
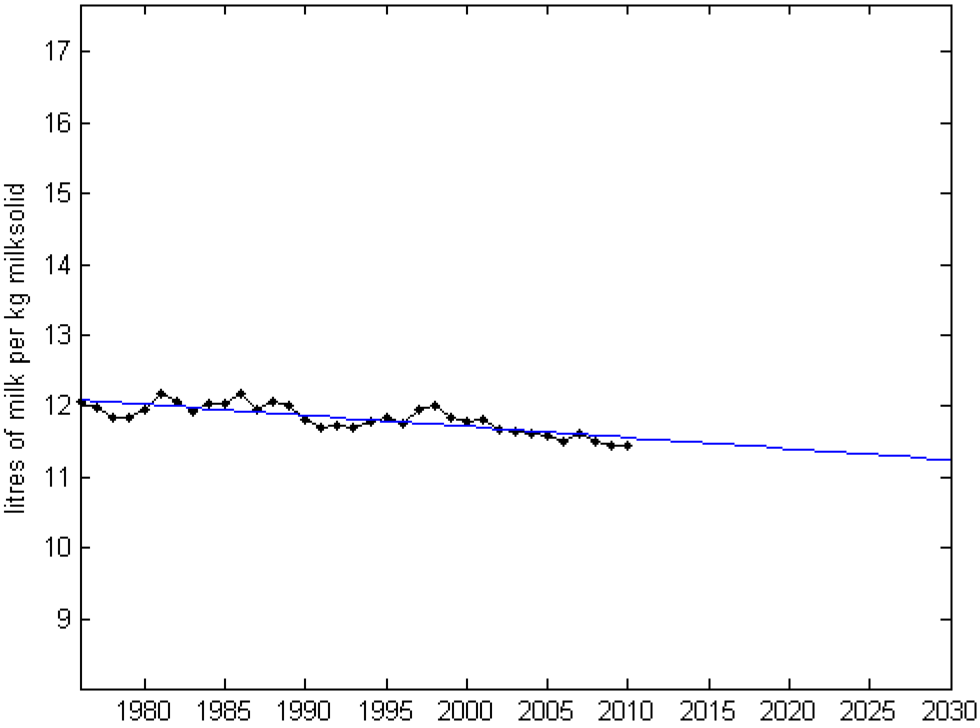
[1] Hendy and Kerr (2005) keep emissions – in their application per animal – from enteric fermentation and livestock deposits separate. We could analogously decompose the implied emission factor for milk, but would gain little by doing so: emissions from enteric fermentation and livestock deposits follow nearly the same trend, so projecting them forward using a single trend is sufficient.



3.2. Milksolid content

The inverse of m_t converts litres of milk into kilograms of milksolids. The conversion is necessary because dairy emissions are measured per litre of milk (reflecting the fact that national dairy production in the inventory is also measured in litres of milk), but the regional production data is in terms of milksolids per hectare. Milk protein and fat content have gradually increased over time, leading to a 5 percent decrease in $1/m_t$ since the late 1970s (LIC & DairyNZ, 2011). In 2010, about 11.46 litres of milk contained a kilogram of milksolids. Figure 2 shows the historical data (of the inverse) as well as the time trend fitted to it to reflect expected future improvements in milk quality. The best-fitting logarithmic trend line is nearly linear in this case.

Figure 2. Litres of milk per kilograms of milksolids



3.3. Dairy productivity

To achieve spatial variability in modelling emissions per hectare, we use dairy productivity data from 17 regions of the country (LIC & DairyNZ, 2011). New Zealand national average productivity has increased by 20 percent in about a decade: from 768 kilograms of milksolids per hectare produced in 1999 to 923 kg/ha in 2010. Figure 3 depicts historical values of productivity as well as the fitted trend lines for each of the 17 regions individually and for New Zealand. The trends are based on 1999-2010 data: we exclude 1998 due to unfavourable weather conditions that caused production per cow to fall to its lowest level since 1992 in that year (LIC & Dairy NZ, 2011).

While productivity in most regions is close to the national average, there clearly are some outliers. The least productive dairy region in 2010 was East Coast with only 538 kg/ha, and the most productive region was North Canterbury with 1249 kg/ha. The wide range of values suggests that it is indeed important to model heterogeneity in productivity (and emissions) in space. North Canterbury is also the region with the fastest productivity growth since 1999. Two regions experienced losses in productivity over the same period: East Coast and Western

Uplands.[2] We attribute the apparent decline to data issues arising from to the small size of these regions. Because we do not believe these decreasing trends will continue, we constrain projections of MS_{it} for these two regions to their respective sample means.

Figure 3. Kilograms of milksolids per hectare

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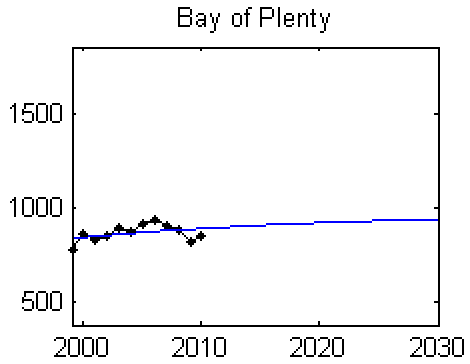
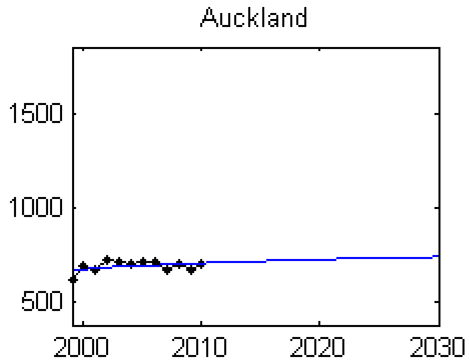
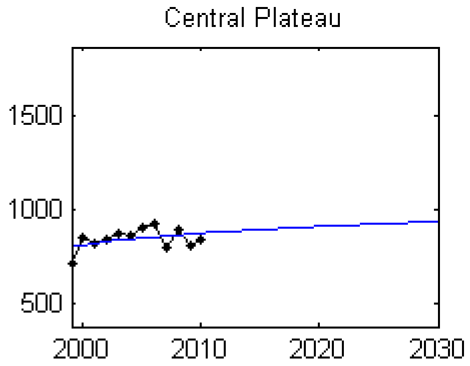
[2] Total dairy production is almost negligible in both regions: only 0.1 percent of New Zealand's dairy cows are held in the East Coast; Western Uplands is the only other region with less than 1 percent of all dairy cows.


Bay of Plenty


Auckland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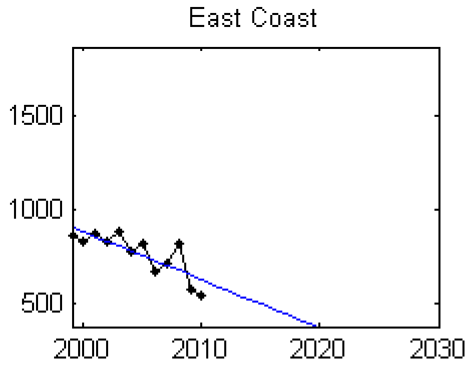
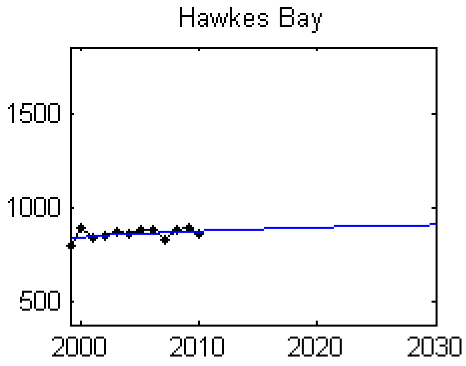
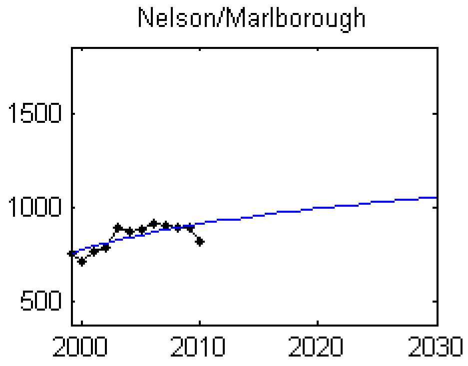
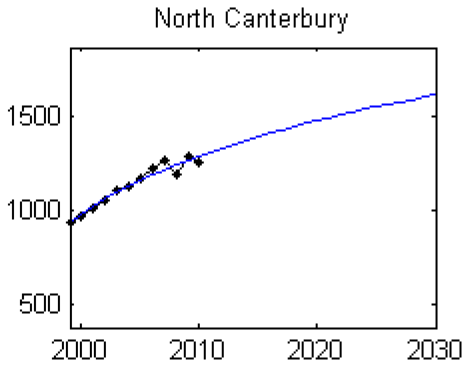
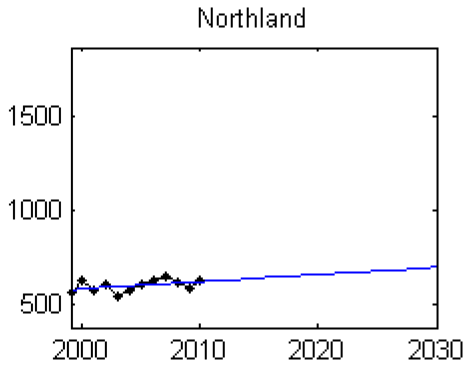
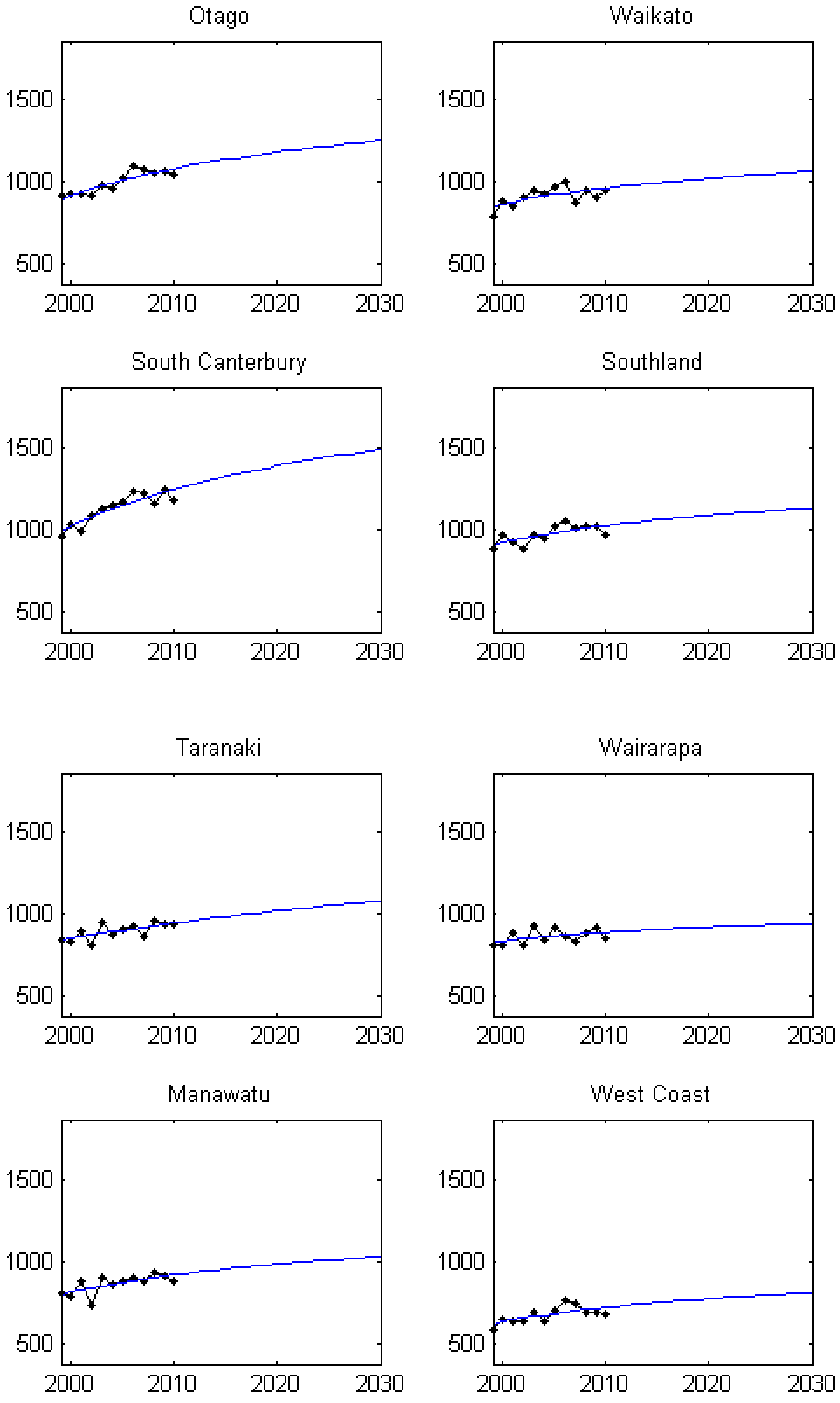

East Coast

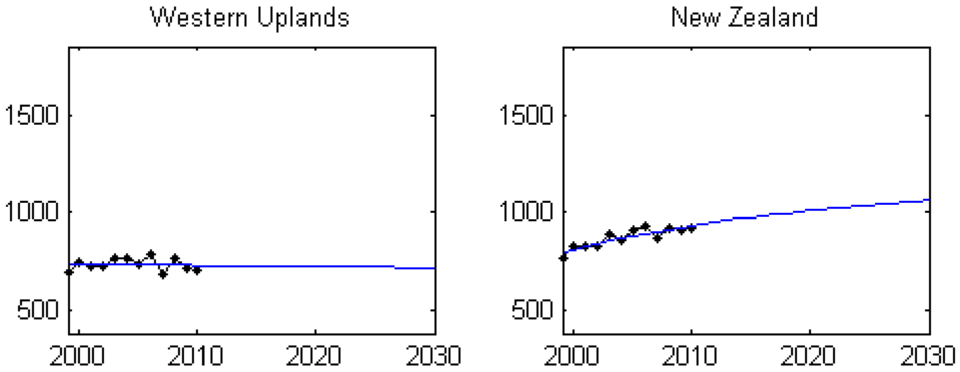

Hawkes Bay


Nelson/Marlborough


North Canterbury


Northland


Otago
Waikato
South Canterbury
Southland
Taranaki
Wairarapa
Manawatu
West Coast
1500
1000
500
2000
2010
2020
2030



National dairy productivity data goes all the way back to 1992. As a robustness check, we compare the national-level time series to the weighted sum of estimated regional trends (projected backward to 1992), where the weight for each region is the 2010 percentage of total effective dairy area found in the region.[3] The comparison is shown in figure 4. Throughout the time period, there is a relatively close match between observed data and the weighted sum of regional projections, suggesting that emissions calculations based on the regional productivity trends will not be significantly different from those that would result from national average productivity figures.

Figure 4. Weighted sum of regional projections versus observed national-level productivity

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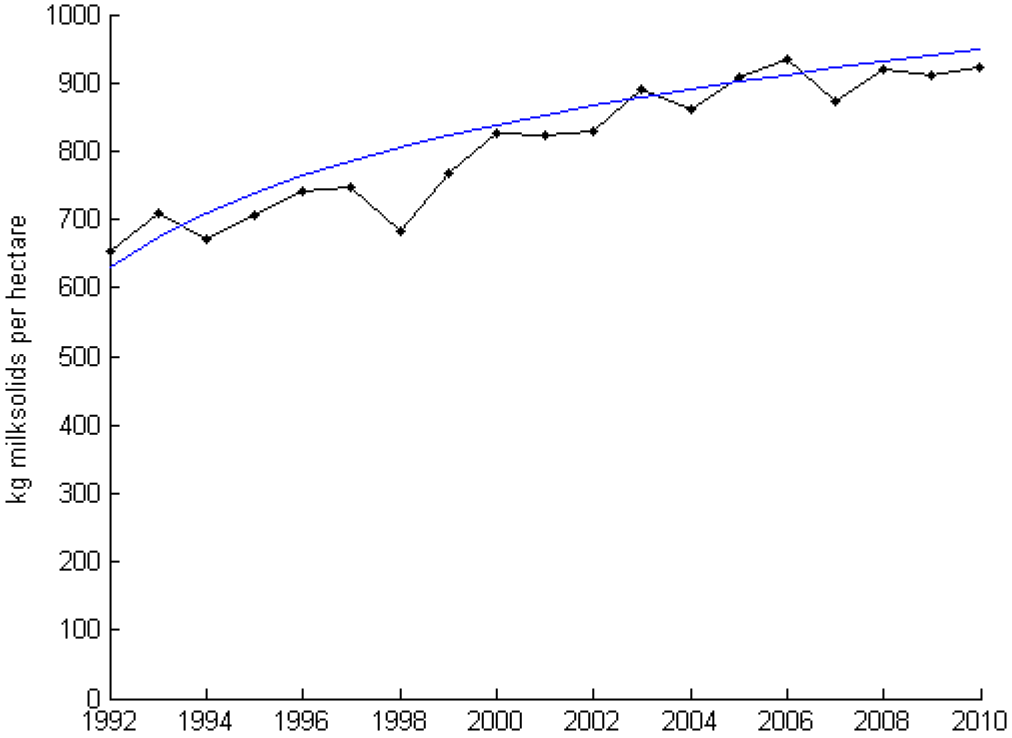
[3] Each region's share of total effective dairy area has changed over time. For simplicity, the weights are based on share observations from a single year, 2010 – these are held constant for the backward projection. Note that the weights are not used in emissions calculations, only for the purposes of the robustness check.



3.4. Implied emission factor for fertiliser

The implied emission factor for fertiliser, IEF^f, represents CO2e emissions per kilogram nitrogen from synthetic fertiliser use, and is calculated from the fertiliser-related formulas in the national inventory. Like the soil N2O component of the IEF for milk, it accounts for direct nitrous oxide emissions from agricultural soils as well as indirect nitrous oxide emissions through atmospheric deposition and leaching (and converts these to CO2e emissions using the appropriate GWP). Because the value of the implied emission factor for fertiliser is determined by physical processes, it does not change through time.

3.5. Dairy fertiliser intensity

Agricultural fertiliser use has nearly quadrupled from 1990 to 2009. We know that this increase comes, in large part, from rising fertiliser intensity within particular land-uses (and some of it from land-use shifting toward higher-intensity uses). However, there is little information available on how fertiliser use has changed within the various pastoral sectors because emissions from synthetic fertilisers are not included under livestock-related emissions in the inventory. Instead, fertiliser-related emissions are reported in a separate category for all agricultural uses combined. Based on these data, it is not possible to ascertain the fraction of fertiliser emissions attributable to dairy farming (or to any other agricultural sector). We therefore utilise crosssectional information on fertiliser use from the Agricultural Census of 2007 to calculate the fertiliser intensity of the dairy sector.

The census contains information, among other things, on the amount of various nitrogen-containing fertilisers used by farm type. For instance, dairy farmers in 2007 applied 281,189 tonnes of urea, 63,407 tonnes of diammonium phosphate, 20,920 tonnes of ammonium sulphate and 94,612 tonnes of other nitrogen-containing fertilisers.[4] The inventory reports fertiliser use not in fertiliser weight, but rather in total agricultural nitrogen use – to make the census data compatible with it, the total nitrogen input from the various fertiliser types needs to be determined. The nitrogen content of urea, diammonium phosphate and ammonium sulphate is known exactly: 0.46, 0.18 and 0.21 by weight, respectively (Parliamentary Commissioner for the Environment, 2004). We first calculate implied nitrogen use across all agricultural sectors from these three fertiliser types, and then allocate the remaining nitrogen (left over after subtraction from 2007 aggregate nitrogen use reported in the inventory) to the all other nitrogen-containing fertilisers category. This allows us to calculate the average nitrogen content (over all agricultural sectors) of other nitrogen containing fertilisers.[5] We assume the nitrogen content of these fertilisers used within the dairy sector is the same, and apply this value to calculate total nitrogen use within dairy farming in 2007. It is then straightforward to determine the sector's fertiliser intensity in 2007: f_{2007}^{d} = 113.62 kg nitrogen/ha.

To model changes in dairy fertiliser intensity over time, we assume constant returns to scale in fertiliser use: this implies that fertiliser intensity increases at the same rate as dairy productivity.[6] Emissions from synthetic fertiliser use represent a relatively small fraction – based on 2007 observations, about 8 percent on average – of total CO2e emissions from dairying and we do not attempt to model regional variation in fertiliser intensity (even though the assumed spatial homogeneity is not completely consistent with our treatment of dairy productivity). Therefore, we derive the dairy fertiliser intensity function simply by appropriately scaling the national dairy productivity trend. The function is illustrated in figure 5.

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[4] The sectoral decomposition we use is based on the ANZSIC 2006 industrial classification.

[5] Hendy & Kerr (2006) ignore other nitrogen-containing fertilisers because the nitrogen content of these fertilisers is not known in advance. By allocating all nitrogen unaccounted for by the use of urea, diammonium phosphate and ammonium sulphate to this group of fertilisers, we implicitly assume that the National Inventory and the Agricultural Census are approximately consistent in their measurement of 2007 fertiliser use. The implied mean nitrogen content of all other nitrogen-containing fertilisers is approximately 0.41 by weight, which is inside the range of values associated with the first three fertiliser types.

[6] An alternative strategy would be to assume that fertiliser *intensity* in sheep and beef farming (calculated in a manner analogous to dairy fertiliser intensity) and total fertiliser *use* in other agricultural sectors are constant, and to attribute all remaining growth in fertiliser use to dairying. These assumptions are, however, clearly untenable because dairy fertiliser intensity calculated in this way is negative for several time periods. Therefore, assuming that fertiliser intensity increases at the same rate as productivity seems more reasonable.

Figure 5. Fertiliser intensity function

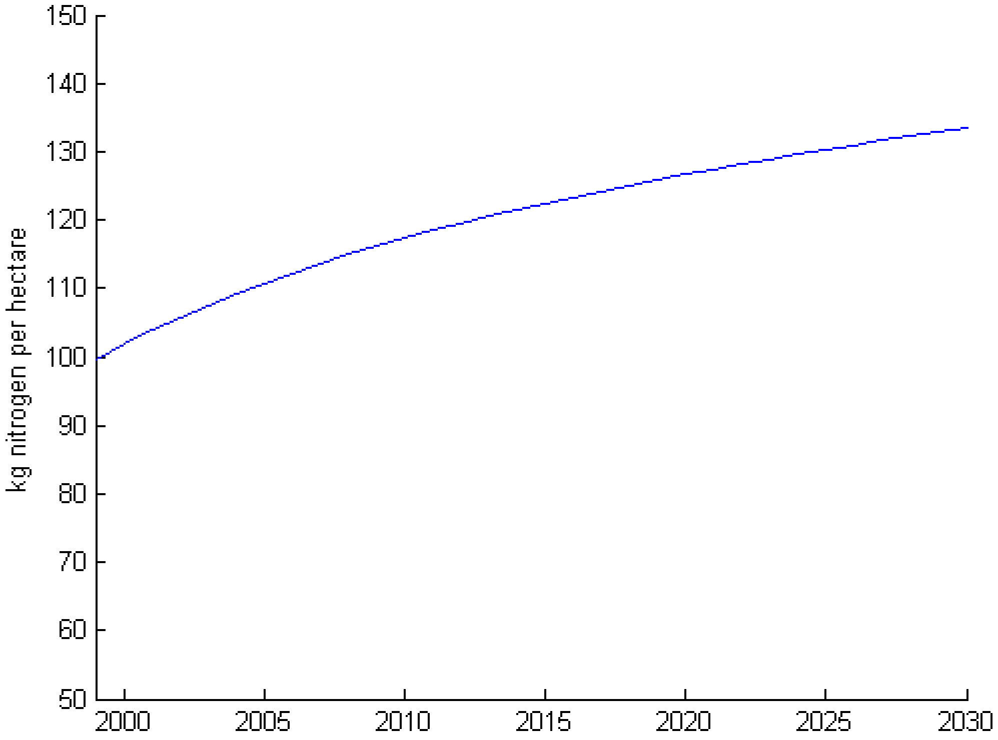


Table 2 Dairy parameter estimates / constants

Variable	Region	*a*	*b*	*c*	constant
IEF_t^d		1.14	-0.14	1980	
$1/m_t$		251.11	-31.50	0	
MS_{it}	Bay of Plenty	662.89	75.24	1989	
	Auckland	555.45	49.65	1989	
	Central Plateau	586.67	93.59	1989	
	East Coast				763.42
	Hawkes Bay	725.95	49.96	1989	
	Nelson/Marlborough	264.82	213.03	1989	
	North Canterbury	-176.17	480.44	1989	
	Northland	-57322.37	7618.00	0	
	Otago	255.36	266.99	1988	
	Waikato	501.40	151.55	1989	

	South Canterbury	154.27	358.21	1989	
	Southland	540.22	158.09	1989	
	Taranaki	-447.74	367.58	1966	
	Wairarapa	641.09	81.00	1989	
	Manawatu	417.50	164.47	1989	
	West Coast	304.11	136.31	1989	
	Western Uplands				732.67
IEF^f					5.50
f_t^d		44.06	24.07	1989	

4. Sheep and beef farming

To model emissions per hectare from sheep and beef farms, we CO2e emissions per hectare of dairy land at location *i* and time period *t*, E_{it}^{sb}, as the sum of livestock- and fertiliser-related emissions:

$$E_{it}^{sb} = r_i[IEF_t^s SR_i] + (1 - r_i)[IEF_t^b SR_i] + IEF^f f^{sb}$$

Each variable on the right hand side of the equation is described in more detail below, while table 3 provides an overview. Table 4 at the end of the section contains the parameter estimates for the functions we use to project these variables forward in time. All annual

Carrying capacity better spatial information

Table 3. Sheep and beef emissions

Variable	Description	Unit of measurement
r_i	Ratio of sheep to sheep-and-beef stock units	scalar
IEF_t^s	Implied emission factor for sheep	kg CO2e/stock unit
SR_i	Stocking rate	stock units/ha
IEF_t^b	Implied emission factor for beef	kg CO2e/stock unit
IEF^f	Implied emission factor for fertiliser	kg CO2e/kg N
f^{sb}	Sheep and beef fertiliser intensity	kg N/ha

4.1. Ratio of sheep to sheep-and-beef stock units

4.2. Implied emission factor for sheep

4.3. Stocking rate

4.4. Implied emission factor for beef

4.5. Implied emission factor for fertiliser

4.6. Sheep and beef fertiliser intensity

Table 3 Sheep and beef parameter estimates / constants

variable	Region / class	*a*	*b*	*c*	constant
ratio of sheep to sheep-and-beef stock units					
	'East Coast class3'				0.6353
	'East Coast class4'				0.6498
	'East Coast class5'				0.6166
	'East Coast class9'				0.6380
	'Marlborough-Canterbury class1'				0.7970
	'Marlborough-Canterbury class2'				0.7520
	'Marlborough-Canterbury class6'				0.7764
	'Marlborough-Canterbury class8'				0.8258
	'Marlborough-Canterbury class9'				0.7768
	'New Zealand class1'				0.8209

	'New Zealand class2'				0.7615
	'New Zealand class3'				0.6540
	'New Zealand class4'				0.5872
	'New Zealand class5'				0.5123
	'New Zealand class6'				0.8003
	'New Zealand class7'				0.9462
	'New Zealand class8'				0.8258
	'New Zealand class9'				0.7017
	'Northland-Waikato-BoP class3'				0.6444
	'Northland-Waikato-BoP class4'				0.4884
	'Northland-Waikato-BoP class5'				0.2339
	'Northland-Waikato-BoP class9'				0.4804
	'Otago/Southland class1'				0.8552
	'Otago/Southland class2'				0.7834
	'Otago/Southland class6'				0.8365
	'Otago/Southland class7'				0.9462
	'Otago/Southland class9'				0.8765
	'Taranaki-Manawatu class3'				0.6902
	'Taranaki-Manawatu class4'				0.6667
	'Taranaki-Manawatu class5'				0.6703
	'Taranaki-Manawatu class9'				0.6750
kg CO2e emissions per stock unit of sheep		23.4193	100.5074	1972	
scaling factor for CCAV (from adding-up constraint)					0.8664
stock units per hectare					CCAV value
kg CO2e emissions per		245.6148	37.9361	1980	

stock unit of beef cattle					
kg CO2e emission per kg N (synthetic fertiliser use)					5.5024
kg N per hectare (synthetic fertiliser use)					12.4745

5. Robustness checks

To check the robustness of our results, we compare them to results derived from other data sources and information published elsewhere. Total CO2e greenhouse gas emissions per hectare for dairy farming and sheep and beef farming have been calculated via a bottom-up approach using OVERSEER and 2010 MAF monitor farm information (Simon – unpublished information). The distribution of these emissions is reproduced in figure X for dairying (blue) and sheep and beef farming (red). We use the top-down approach presented in equations 1 and 2 along with simulated 2010 land-use data to obtain an analogous distribution of per-hectare emissions, and plot the results in figures X and X.

We do not expect to observe a perfect match between the bottom-up and top-down frequency distributions for several reasons. First, our calculations are not carried out at the farm level. For dairying, we only use highly aggregated data which means that we are able to capture less variability in emissions than a farm-based model. In contrast, we model stocking rates at a finer-than-farm scale for sheep and beef farming (and other variables at a regional or national scale). Second, for lack of 2010 observations we employ simulated land-use data, while MAF monitor farms have a known land use. Third, the sample of MAF monitor farms is not necessarily representative of the population of New Zealand farms, and their emission outcomes were not calibrated to inventory totals. We would thus expect to see some differences between the two distributions even without the differences in methodology.

Figure Emission per hectare in tonnes of CO2e

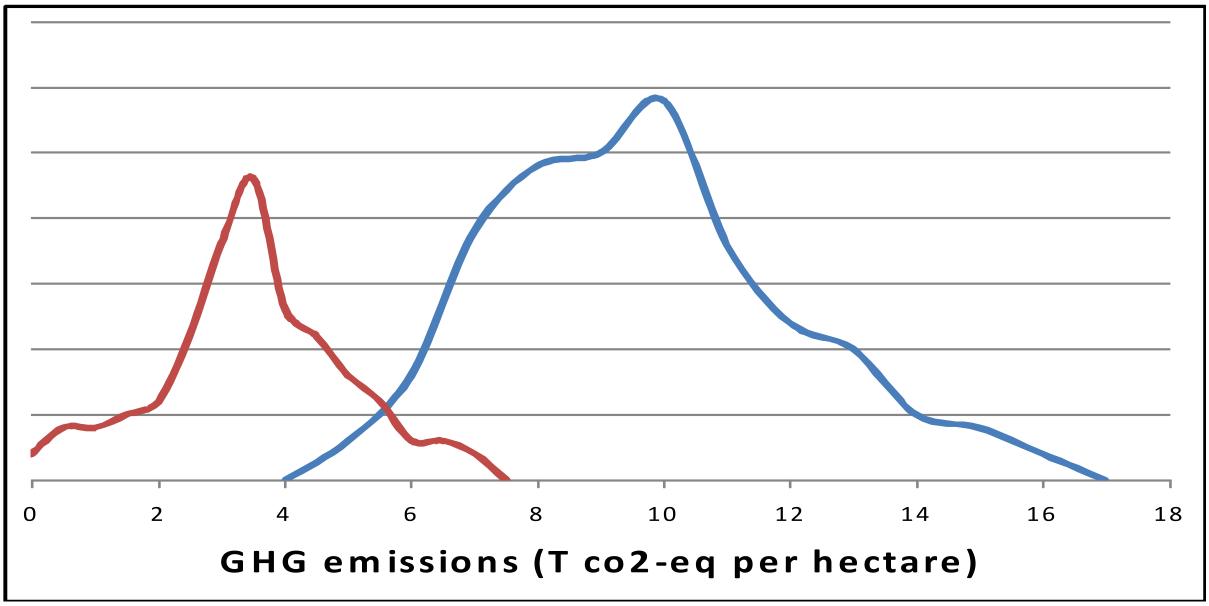


Figure Histogram of modelled 2010 dairy emissions per hectare (tonnes CO2e)

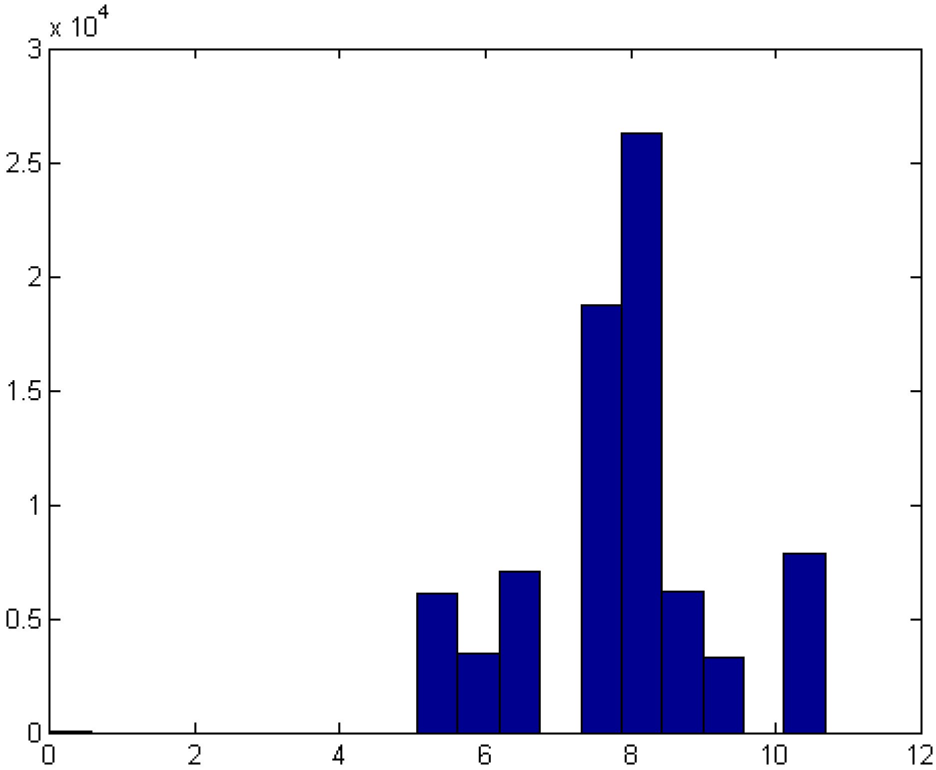
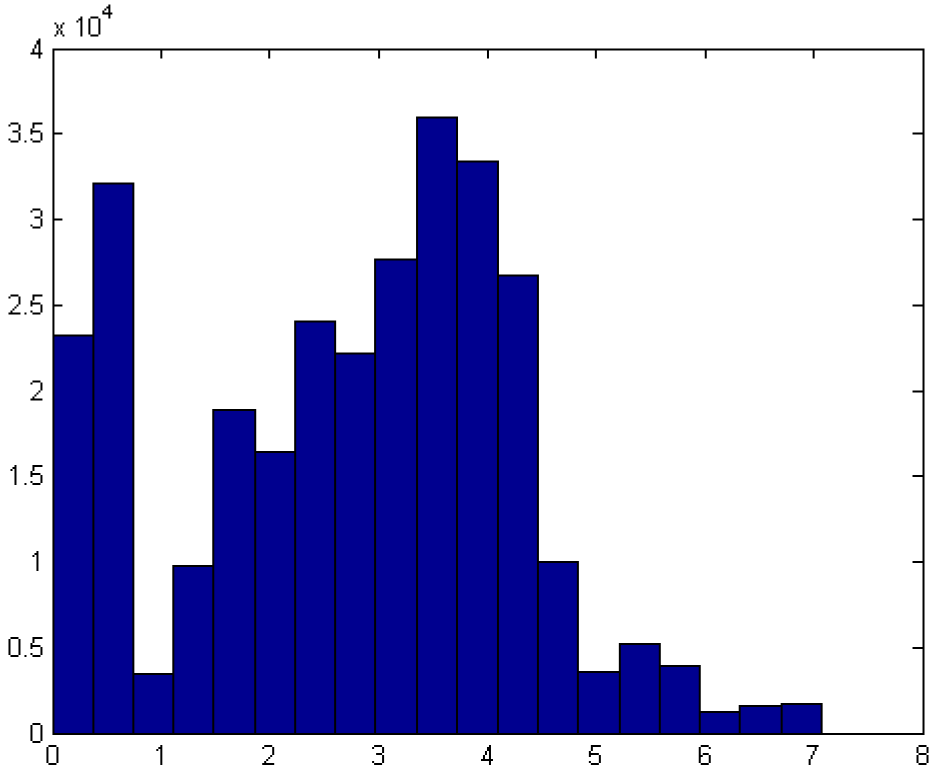


Figure Histogram of modelled 2010 sheep and beef emissions per hectare



As expected, the histogram of dairy emissions displays a lower range than the distribution derived from monitor farm data. Recall that we do not model intra-regional variation in emissions per hectare: the range of the regional means is naturally lower than the range of farm-level emissions. The mode and mean of the two distributions are similar, but they do not coincide exactly. Differences in methodology and the fact that the sample of monitor farms is not representative could explain these differences.

Sheep and beef emissions have a nearly identical range and mode in figures X and X, and the shape of the distributions is also similar except for a large number of cells that are projected to produce near-zero emissions by our top-down approach in equation X. These represent sheep and beef land with low carrying capacity and hence low modelled stocking rates.[7] It is likely that some of these cells comprise the lowest-quality areas of larger farms, which explains why the low-emission peak does not show up in the distribution of farm-level emissions: the average per-hectare emissions of the farm are indeed higher. Timar (2011) offers an additional observation that may partially explain the difference. He notes that abandoned pasture could in some cases be miscategorised as sheep or beef land in the land-use dataset because it is based, in large part,

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[7] Carrying capacity is not one of the factors used in LURNZ for allocating land uses spatially, which raises the possibility that the large number of low-emission cells indicates a problem with our simulated 2010 land use map. However, a similar fraction of observed (2002) sheep and beef cells have a comparably low carrying capacity.

on remote sensing imagery. The classification error would make pastoral farming appear more attractive on marginal land, affecting both observed and simulated land use maps. Therefore, some of the low-emission cells in figure X may in fact be scrub areas as opposed to land used for livestock farming.

Comparison to MAF emission factors
Comparison to past inventory totals
Etc...