Estimating Co-benefits of Agricultural Climate Policy in New Zealand: A Catchment-Level Analysis*

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ABSTRACT

This paper uses an economic catchment model to assess changes in land use, enterprise distribution, greenhouse gas emissions and nutrient loading levels from a series of policies that introduce carbon prices or nutrient reduction caps on land-based production in the Hurunui Catchment in Canterbury, New Zealand. At \$20/tCO_2e, net revenue for the catchment is reduced by 7% from baseline levels while GHGs are reduced by 3%. At \$40/ tCO_2e, net revenue is reduced by 15% while GHGs are reduced by 21%. Nitrogen and phosphorous loading levels within the catchment were also reduced when landowners face a carbon price, thus providing other benefits to the environment. Additional scenarios in this paper assess the impacts from developing a large-scale irrigation project within the catchment. Results show that while adding irrigation can improve farm output and revenue, it also results in dramatically higher GHG emissions and nutrient loads. Placing a carbon price on land-based activities diminishes some of these pollutants, but not at the same rate as when the policy what enacted on the baseline irrigation levels. Finally, we investigate the impacts of imposing a nutrient loading cap on farm activities instead of a carbon price and find that if landowners had greater access to irrigation but were constrained to hold the nutrient loads at baseline levels, revenue could increase by 6% over the baseline while GHG emissions could be reduced by 5%. Our findings suggest that while there is a potentially a strong trade-off between water quantity and water quality in the Hurunui Catchment, imposing the right policy levers could reduce some of the environmental impacts from an increase in land-use intensity without placing a large economic or regulatory burden on its landowners.

KEYWORDS: Agriculture and Forestry Modelling, Land Use, Climate Policy, Greenhouse Gas Emissions, Water Quantity, Water Quality

INTRODUCTION

Agriculture is an important part of New Zealand's economy, and the sector faces similar challenges are other large producing countries of the world as it strives to maintain or enhance the level of output while keeping its resource use and environmental integrity in check. The country is unique from a regulatory perspective though as it implemented a climate policy in 2008, tghe New Zealand Emissions Trading Scheme (ETS), which already covers many major sectors of the economy, including forestry. Because approximately 47% of New Zealand's greenhouse (GHG) emissions occur in the agricultural sector (MfE, 2011), agriculture is scheduled to enter the ETS in 2015. Discussions are currently underway on developing a way to bring this sector into the ETS and meet emissions targets without placing a large burden on its stakeholders. This paper uses an economic model to assess potential economic and environmental impacts of a climate policy on land-based production in a Canterbury, New Zealand catchment.

Despite the importance of the agricultural and downstream processing sectors in the New Zealand economy, there is not a strong tradition of using partial or general equilibrium models to evaluate domestic policies or other measures directed at the agricultural sector. Policy-makers have instead relied on the development of ad hoc scenarios of land use change, farm budget models, and simple multiplier analysis of flow-on effects. To redress this situation, we have developed a catchment-scale partial equilibrium framework that is capable of assessing both economic and environmental impacts of a variety of policies that could affect regional land use and rural livelihoods.

This paper uses the New Zealand Forest and Agriculture Regional Model (NZ-FARM), a comparative-static, regional, non-linear mathematical programming model of regional New Zealand land use, to assess the economic and environmental impacts of a GHG emissions reduction policy at the catchment level. We do this by imposing a series of carbon prices on GHG emissions at the farm activity level for the Hurunui Catchment in Canterbury, New Zealand. The model's structure is similar to that of the US Department of Agriculture's Regional Environment and Agricultural Planning

(REAP) model (Johansson et al., 2007). The model maximizes income from land-based activities across a catchment, accounting for the environmental impacts of land use and land-use changes. It can be used to assess how changes in technology (e.g., GHG mitigation options), commodity prices, resource constraints (e.g., water available for irrigation), or how proposed farm, resource, or environmental policy could affect a host of economic or environmental performance indicators that are important to decisions-makers, land managers and communities.

This analysis is unique because, unlike proposed climate policies in North America and Europe where landowners can generally voluntarily enlist in a climate program to receive offset payments for changing their practices from business as usual, the New Zealand government has mandated that agriculture be regulated under a now operational ETS beginning in 2015. In addition, forests established before-1990 are already regulated under the ETS, while post-1990 forests can be voluntarily enrolled in the programme. Thus, the potential changes to land use in New Zealand could be significant and serve as an important guide to other regions of the globe that are considering similar policies in the future. Additionally, using NZ-FARM to model climate policy on land use allows us to assess the potential co-benefits on the catchment's land and water, such as changes in fertilizer application and nutrient loading levels. These findings could be used to assess whether it is necessary to impose additional environmental regulations on land use within the catchment, or whether a climate policy could provide the co-benefits of nutrient reductions as well.

In addition to looking at the co-benefits of GHG reduction policies, this paper also assesses the potential impacts from implementing a large water storage infrastructure project proposed for the same catchment that could nearly double the area of irrigated land. This application is timely, given that there are increasing pressures on water resources in the catchment, and frequent conflicts between abstractive users (mainly pastoral), recreational (e.g. kayaking, fishing) users, and environmental needs such as improvements in biodiversity and other ecosystem services. At the same time that the irrigation infrastructure project is being promoted, water quality limits are also being developed for the same catchment to constrain nitrogen and phosphorous loadings.

Concurrently imposing an emission and nutrient reduction policy and promoting the increase in land use intensity could have a dramatic impact on land use and farm income.

Studies have been conducted to assess the economic and environmental impacts of changes in GHG emissions, water use, and nutrient loading in New Zealand, but only a few have been developed to address this issue at the catchment level. Kerr and Zhang (2009) review empirical studies on the impacts of a carbon price on NZ agriculture and conclude that a carbon price of $25[1] per ton of carbon dioxide equivalent (tCO_2e) would impact the profitability of dairy and sheep-beef farms but still not be high enough to induce significant changes in production intensity or land use. Rae and Strutt (2011) use a CGE-model for New Zealand to simulate a range of scenarios involving changes in fertiliser use and stocking rates on dairy farms to reduce the nitrogen balance from between 10% to 30%. They find that value added for just the dairy farm sector could fall between 2% and 13%, while export earnings from dairy products may fall by between US$269 million and US$1,145 million. Tee et al. (2011) looked at the impacts of a carbon price on radiata pine forests in New Zealand and found that the value of land employed in forestry planted before 1990 increases significantly at a modest price of $10/$tCO_2e$, but do not investigate where additional forestland would come from. NZ-FARM has the ability to investigate both the important economic and environmental impacts of climate policy as well as detailed land use and farm activities at the catchment level.

There have also been few studies on comprehensive impacts of water infrastructure projects in New Zealand at the catchment level. Lennox (2011) uses a CGE model to estimate the economic impacts of constraints on water supply for irrigation in the greater Canterbury region and finds that an increase in the scarcity of water would have a negative impact on dairy farming, whilst other sectors would increase output because they are less water intensive. An econometric study of the Mackenzie Basin, in inland south Canterbury, found that rights to irrigation water could generate a land sale price premium up to 50% relative to similar land without irrigation (Grimes and

[1] All monetary values are listed in New Zealand dollars, unless specified otherwise. At time of publication, exchange rates were as follows: 1 NZD = 0.81 USD, 0.54 EUR, and 0.74 AUD.

Aitken, 2008). Ex post evaluations of specific irrigation schemes in Canterbury found significant socio-economic benefits for improved irrigation in the region (Ford, 2002; Harris et al., 2006). None of these studies have investigated the issue of water management in Canterbury at the level of detail available in NZ-FARM.

The paper is organized as follows. First, we present the theoretical foundation of the NZ-FARM model, and describe the details of the data sources specific to the catchment. Next, we describe the GHG and nutrient mitigation options for the catchment as well as issues surrounding water management specific to the catchment or wider Canterbury region. Following that, we present baseline land use, farm production, GHG emissions, water use, and other environmental outputs, followed by results from a series of policy scenarios. The final section provides a conclusion of our findings.

NZ-FARM MODEL

The New Zealand Forest and Agriculture Regional Model (NZ-FARM) is a comparative-static, mathematical programming model of regional New Zealand land use. Production activities in each region of NZ-FARM are differentiated in a variety of ways, including a set of fixed and variable input costs, use of inputs such as fertilizer and water, and output price. Production and land use are endogenously determined in a nested framework such that landowners simultaneously decide on the optimal mix of land use for their fixed area, given their land use classification (LUC) and soil type, and then how to allocate their land between various enterprises such as grains, livestock, and horticultural crops that will yield them the maximum net return for their land use. Two other land uses are also tracked in the model; Manuka-Kanuka (scrub) land, which is allowed to vary across scenarios, and Department of Conservation (DOC) land that is assumed to be fixed as land use change for DOC is not typically driven by economic forces. The model is written and maintained in General Algebraic Modeling System (GAMS). The baseline calibration and estimates for the scenario analysis in this paper are derived using the non-linear programming (NLP) version of the COIN IPOPT solver. More information on the model specifications particular to the catchment is provided below.

Objective Function

The core objective of the model is to determine the level of production outputs that maximize the net revenue (NR) of production across the entire catchment area subject to the cost of production inputs, land available for production, and water available for irrigation. Formally, this is:

$$Max\ \text{NR} = \sum_{R,S,E,I,F,M,IO} \begin{matrix} \text{Output Price*Output Quantity} \\ -\text{Livestock Input*Unit Cost} \\ -\text{Variable Cost*Unit Cost} \\ \text{-Annualized Fixed Costs} \\ \text{-Land Conversion Cost*Hectares Converted} \\ +\text{Forest Carbon Sequestration Payments} \end{matrix}$$

Subject To:

$\text{Inputs}_R \leq \text{Inputs Available}_R$

$\text{Land Use}_R \leq \text{Land Available}_R$

$\text{Irrigated Enterprises}_R \leq \text{Irrigated Land Available}_R$

$\text{Environmental Outputs}_R \leq \text{Regulated Environmental Output}_R$

where IO is a set of enterprise input costs and output prices, E is enterprise, I is irrigation scheme, S is soil type, F is fertilizer regime, M is mitigation practice, and R is region. Summing across all sets yields the total net revenue for the entire catchment.

Production activities in each region are differentiated in several ways. Each production activity uses information on input cost, input use, and output price. As mentioned above, production and land use are endogenously determined in a nested framework (Figure 1). First, landowners decide on the optimal land mix for their fixed area within a sub-zone, given their soil type. Second, the landowner determines the allocation of land between various enterprises such as grains, livestock, and fruits and vegetables that will yield the maximum net return for his land use. Last, the decision is made on what outputs to produce given the mix of enterprise and output price.

The allocation of land to a specific land use, enterprise, and product output is represented with constant elasticity of transformation functions (CET). The transformation function essentially specifies the rate at which regional land inputs, enterprises, and outputs produced can be transformed across the array of possibilities. The CET function itself is calibrated using the share of total returns for each element included in the stage and a parameter, σ_i, where $i \in \{L, L2E, E\}$ for the three separate nests, land (L), land to enterprise (L2E), and enterprise to output (E) . In general, CET parameters can range from 0 to infinity, where 0 indicates that the input (land, enterprise) is fixed, while infinity indicates that the inputs are perfect substitutes. The CET functions used in NZ-FARM are parameterized based on the estimates from existing literature of regional economic land use models (e.g., Johansson et al. 2007). In our case, CET values ascend with the level of the nest, as a landowner likely has more flexibility to transform its enterprise mix compared to changing the share of land use (e.g., forest v. pasture).

Finally, NZ-FARM tracks several environmental outputs to estimate the impacts on land use and enterprise mix given a specific carbon price or environmental regulation. In the climate arena, the model can account for the following mitigation options: (1) extended rotations for forest plantations or tax for harvests; (2) a direct tax on agricultural inputs such as fertilizers or pesticides; (3) the reduction of CH_4 and N_2O from livestock through manure management and installation of feed pads; (4) the reduction of N_2O through the application of nitrogen inhibitors (DCDs); and (5) improving farming efficiency and altering stocking rates. In addition, the model can track changes in nitrogen (N) and phosphorous (P) leaching rates from various land uses and farm management practices.

HURUNUI CATCHMENT DATA

Data for the inputs used for the catchment in NZ-FARM was obtained from several sources. A list of all the different sets for which data was obtained (enterprise, soils, etc.) is shown in Table 1. Sources of these data are discussed in the following subsections. In total, there are nearly 1200 combinations of enterprise, input, and mitigation options modelled for the Hurunui catchment.

Geographic Area and Land Use

This paper focuses on Hurunui catchment in North Canterbury, New Zealand. The catchment area is divided into 3 sub-catchment zones based primarily on biophysical properties derived based on LUC classes from New Zealand Land Resource Inventory (NZLRI) data and availability of water for irrigation. These areas include the plains, foothills, and hills. A map of the catchment is shown in Figure 2. Land in each zone is categorized by six distinct uses: forest, cropland, pasture, horticulture, scrub, and Department of Conservation (DOC) land. Baseline land use was provided by Environment Canterbury (October 2010).

Enterprises, Inputs, Outputs and Prices

Enterprises tracked in the model cover most of the agricultural and forestry sector for the catchment. Key enterprises include dairy, sheep, beef, deer, timber, maize, wheat, and fruit. NZ-FARM includes 18 enterprises for the Hurunui Catchment, however each catchment zone has only a subset of practices that can be undertaken. These sets are determined by bio-geographical characteristics like slope, soil type, access to water, etc.

Each enterprise requires a series of inputs to maximize production yields. The high cost of given inputs coupled with water and input constraints can limit the level of output from a given enterprise. Outputs and prices are primarily based on data provided by Lincoln University (2010), Ministry of Agriculture and Forestry (MAF) farm monitoring report (2010), and the 2010 State of New Zealand Agriculture and Forestry (SONZAF), and are listed in 2009 New Zealand dollars (NZD). Stocking rates for pastoral enterprises were established to match figures included in the FARMAX model (Bryant et al., 2010). Each enterprise also faces a large set of fixed and variable costs ranging from stock replacement costs to deprecation that were obtained from personal communication with farm consultant Stuart Ford, Ministry of Agriculture and Forestry (MAF) farm monitoring report (2010) and Lincoln University (2010). The cost series was developed for each enterprise and varied across all three zones. Altering the cost of inputs or price of outputs as well as the list of enterprises available for a given region will change the distribution of regional enterprise area, but the total area is constrained to remain the same across all model scenarios.

Fertilizer and Mitigation Options

Most enterprises in the catchment have the option to vary the use of fertilizer. This model tracks changes in product and environmental outputs from changes in fertilizer for the following applications: 100% of recommended N and all other fertilizers, 80% of recommended N but 100% of recommended application of all other fertilizers, 60% of recommended N but 100% recommended application of all other fertilizers, 50% of recommended N but 100% recommended application of all other fertilizers, no N application but 100% of recommended application of all other fertilizers, 0% of recommended lime but 100% of recommended application of all other fertilizers, and finally, no fertilizer application. The physical levels of fertilizer applied were constructed from a survey of farmers in the greater Canterbury region (Ford, 2010).

NZ-FARM also has the option to differentiate between 'business as usual' (BAU) practices and other production practices that can mitigate/reduce greenhouse gases (GHGs) and other environmental pollutants. Some of these mitigation options result in a decline in productivity, while others increase farm productivity and/or cost more than business as usual practices. The current array of options modelled is:

- Adding DCDs (N inhibitors),
- Constructing feedpads at dairy farms,
- Providing payments for forest carbon sequestration.

Environmental Outputs

The model has the ability to track environmental outputs such as nitrogen and phosphorous leaching, N_2O emissions from excreta and effluent, and CO_2 emissions from fuel, electricity and fertilizer used in the production process. Data on environmental output coefficients were obtained from several sources. Nitrogen and Phosphorus leaching rates for pastoral farming were obtained from the most recent version of OVERSEER (2010), while N and P leaching rates for all other enterprises were constructed using SPASMO (2010). Forest carbon sequestration rates were derived from regional lookup tables for a 300 index scaled radiata pine pruned[2], medium fertility site (Paul et al., 2008). GHG emissions for all other enterprises were derived using the IPCC's *Good Practice Guidance* (2000).

CARBON PRICE AND IRRIGATION SCENARIOS

The current ETS in New Zealand covers all major sectors of the economy, with the exception of agriculture that is due to be regulated in 2015. Besides forestry, most emissions are covered through an upstream point of obligation on fossil fuels. For this analysis, we impose a climate policy on agriculture through a unit price per tonne of GHG emissions ($\$/tCO_2e$) for all farm inputs (e.g., fertilizer), livestock activity (e.g., beef and sheep grazing), and energy used in primary production (e.g., fuel for tractors and electricity for irrigation). All activities conducted outside the farm gate, such as the production of fertilizer or transportation of output to the processing plant, are not covered in this analysis. The ETS spot price as of May 2011 was about $\$20/tCO_2e$, and as a result we restrict our analysis to carbon prices of \$20 and $\$40/tCO_2e$.

The current level of irrigated area in the Hurunui catchment used for the baseline scenario is about 22,000 ha. Nearly all of this is centred in the plains region, where a majority of the area's agricultural output is produced, including 98% of the catchment's airy production. Lack of additional water available for irrigation in the region means that there is little (if any) additional water available to be allocated. This has led not only to a large difference in farm incomes for farms with and without irrigation, but to recent demands from landowners for additional supply-side development that would allow them to begin irrigating, expand their current irrigation or increase the reliability of their water supply. One proposal from the Hurunui Water Project to improve the water supply situation has been to build a dam on the South Branch of the Hurunui River (costing upwards of \$42 million) and/or to construct a control weir (costing about \$3 million) at the outlet of Lake Sumner in the western part of the catchment (See Figure 4). A recent study of this proposal commissioned for

[2] A 300 Site Index is a typical volume measurement for radiata pine in New Zealand, representing the mean annual volume increment, in $m^3/ha/yr$, of a stand at an age of 30 years, assuming a final stocking of 300 stems/ha

the purpose of this research found that this could increase the amount of irrigated land in the region on average to about 42,000 hectares (Aqualink, 2010).

The two key irrigation scenarios we assess are the baseline with 22,000 ha of irrigated land (BASE) and a proposed scheme that would increase the amount of irrigated land to 42,000 ha (IRR), based on the Aqualink (2010) study. While New Zealand regulations dictate that farmers must obtain resource consents for irrigated land that are typically given on a first-come, first-served basis, we make no assumptions about how those consents are granted. Each of these irrigation scenarios are also conducted with a carbon price of $20 and $40 t$CO_2$e (e.g., BASE_20, IRR_40). Finally, we estimate the impacts of implementing a nutrient cap instead of a carbon price by conducting as scenario with increased irrigation but where N and P outputs are constrained to the baseline level of irrigation with no carbon price (N+P_CAP). In this scenario, nutrient loading permits are can be traded across enterprises and land uses but not across zones.

BASELINE AND SCENARIO ANALYSIS

Baseline

The entire catchment comprises 258,800 ha, of which 22,000 ha are irrigated. Almost all (99.7%) of the base irrigation occurs in the plains area, as that is typically the zone with the highest productivity and revenue potential. The other 0.3% of irrigation occurs in the foothills. Total catchment income derived from baseline figures for input costs, output prices, and current enterprise productivity is estimated at 225.2 million NZD. Regional output is shown in Table 2. Sheep and beef farming is dominant in the dryland foothills, while most other production occurs on the irrigated plains.

Land use in the catchment is dominated by pasture in the plains and foothills, and by Dept. Of Conservation managed land in the higher and steeper hill region. Plantation forests encompass very little of the land in the catchment, as do arable cropland and horticultural land. Scrubland comprises about 12% of total land use in the catchment and thus has the largest capability of being converted to other uses[3]. The total area and distribution of baseline land use by zone is listed in Table 3.

The total and net greenhouse gas emissions for the Hurunui catchment are listed in Table 4. The bulk of emissions come from non-CO_2 gases in the livestock sector, which is typical for most agriculture-intense catchments in New Zealand. As in the latest NZ GHG Inventory (2011), enteric fermentation is the largest source of emissions, followed by N2O from agricultural/grazing soils. Annual carbon sequestration from both plantation and indigenous forests nearly cuts the net emissions in half.

POLICY SCENARIOS

The following sections discuss the findings from the policy scenarios for the Hurunui Catchment with carbon prices, added irrigation, and nutrient and GHG caps. The area of major land use and enterprise for the entire catchment are shown in figures 5 and 6, while the relative change in revenue, GHG emissions, and nutrients compared to the baseline are shown in figure 7.

Baseline irrigation with carbon price

The initial carbon policy scenarios impose a carbon price of \$20 and \$40/tCO_2e on GHG emissions for all stages of production at the farm level. For forest plantations, landowners receive a credit for carbon sequestered beyond the baseline from changes in forest management or adding new plantations, but must submit a payment for felling trees and converting to another land use. At \$20/tCO_2e, net revenue for the catchment is reduced by \$16.7 million (-7%) while GHGs are reduced by 28.2 thousand tCO_2e (3%). Land use shifts from horticulture (-8%) and scrub (-3%) to cropland (8%) and forest (3%). At \$40/tCO_2e, net revenue is reduced by 15% while GHGs are reduced by 21% from baseline levels. Comprehensive land use change for the higher carbon price scenario is from scrub (-3%) and pasture (-6%) to cropland (82%), forest (49%), and horticulture (32%). This finding indicates that not only are the economic and environmental impacts to an increase in carbon prices non-linear, but also the directional changes in land use are not always consistent.

[3] Note that for this study we hold DOC land fixed, so it must remain constant for all scenarios.

Additional irrigation

The increased irrigation scenario (IRR) added reliable access to water for 20,000 additional hectares in the catchment, an increase of about 91%. All of this increase is expected to occur in the plains zone, increasing the region's proportion of irrigated land to more than 55%. Total catchment income is estimated at $244 million, an increase of $18.5 million (8%) over the base case. Net GHG emissions could increase by more than 200 000 tCO_2e (24%) as a result of changes in land-use intensity, while N and P leaching increase by 15% and 5%, respectively. Although the amount land in the plains used for dairy enterprises increases by about 1,500 ha (10%), land use is estimated to shift from pasture and horticulture to forest and cropland. Land use for the foothills and hills zones remains the same as the baseline as there is no change in irrigated area. These findings indicate that while improving water storage infrastructure can increase overall farm income and output, it can have a dramatic impact on the level of GHG and nutrient outputs within the catchment as well.

Additional irrigation with carbon price

Results for the increased irrigation scenario with carbon prices of $20/$tCO_2e$ (IRR_20) and $40/$tCO_2e$ (IRR_40) are not as dramatic as the irrigation scenario with no carbon price. For the IRR_20 scenario, total revenue for the catchment is $222 million, a change of -1% from the baseline with no carbon price but an increase of 7% over the baseline scenario with the same carbon price. Total GHG emissions increase by 174 thousand tCO_2e (20%), while N and P leaching increases by 15% and 5% respectively. As in the IRR scenario, the area of dairy enterprises increases (11%), but overall land use in the plains region primarily shifts from pasture to cropland and forests.

The irrigation scenario with a carbon price of $40/$tCO_2e$ produces and estimated revenue of $201.8 million for landowners, a change of -10% and +5% compared to BASE and BASE_40, respectively. GHG emissions increase by 19%, while N increases by 14% and P leaching has a 5% gain compared to the base. Again, land use shifts to dairy, cropland, and forests from other pasture and horticulture. These findings indicate that although implementing a carbon price can reduce GHG emissions and N (but not P) loading levels relative to an irrigation scenario without a carbon price, overall nutrient outputs are still significantly higher than the baseline. This suggests that simply implementing a carbon tax on farm inputs or an equivalent incentive via the ETS will not necessarily keep these nutrient outputs at (or below) baseline levels. Additionally, this policy approach does not induce the same level of absolute reductions in nutrient loads that a carbon price with baseline irrigation levels could provide.

Additional irrigation with nutrient loading cap

The N+P_CAP scenario allows irrigation in the catchment to increase to 42,000 ha, but restricts N and P loading limits in a given region to baseline levels. This allows some flexibility for landowners as they are allowed to trade their allocated permits for N and P within the catchment. Model results indicate that net revenue for the catchment would be $239.1 million, an increase of 6% over the baseline, but a 2% decrease compared to IRR. GHG emissions decrease by 5% compared to the baseline, while nutrient levels equal the baseline. Land use shifts from pasture and scrub to horticulture, forestry, and cropland. In fact, the area of forests more than doubles over the baseline level, suggesting that landowners are willing to plant more forests and use the credits to offset some of their increases in nutrient loading in other areas of the catchment. This increase in forestland promotes both a conservation of N and P leaching as well as an increase in carbon sequestration.

CONCLUSION

This paper uses an economic catchment model to assess changes in land use, agricultural output, and environmental factors from several climate change and nutrient loading policies in the Hurunui Catchment of North Canterbury, New Zealand. First, we investigate the potential impacts of imposing a carbon price on farm-level activities. At \$20/tCO_2e, net revenue for the catchment is reduced by \$16.7 million (7%) while GHGs are reduced by 28.2 thousand tCO2e (3%). At \$40/ tCO_2e, we find that net revenue is reduced by 15% while GHGs are reduced by 21%. Changes in land use were not always consistent though as a carbon price of \$20/tCO_2e induces shifts from horticulture and scrub to cropland and forests, while the \$40/tCO_2e scenario saw larger shifts from scrub and pasture to cropland, forest, and horticulture. These findings indicate that not only are the economic and environmental impacts to an increase in carbon prices non-linear, but also the directional changes in land use are not always consistent.

In addition to imposing a carbon price on GHG emissions produced from farm activities, we also use NZ-FARM to estimate the potential impacts of increasing the amount of irrigated area developed from a proposed infrastructure improvement project. Results show that increasing the amount of water available for irrigation by as much as 91% will generally affect the more fertile plains sub-catchment. Land use is expected to shift out of scrub and pasture to arable crop and horticultural land as well as forest plantations. Total catchment income is expected to increase by about 8% over baseline levels if the new irrigation scheme is implemented, but GHG emissions and total N and P loading levels are all expected to significantly increase as well. Even with the introduction of a carbon price on farm activities, environmental outputs are higher than the baseline case with less irrigation and no climate policy imposed on the sector. This indicates that while the new infrastructure to improve water quantity in the region provides an overall benefit to landowners directly involved in agriculture, it could also increase costs to other sectors of the local economy that are reliant on good water quality as well as New Zealand as a whole, which is investigating ways to effectively reduce its comprehensive GHG emissions.

Finally, we investigate the potential impacts and efficiency of imposing a nutrient loading cap on farm activities relative to a carbon price. If landowners had greater access to irrigation but were constrained to hold the zone-wide nutrient outputs at baseline levels, revenue would increase by 6% over baseline levels while catchment-level GHG emissions could actually be reduced by 5%. Thus, a nutrient cap could be used to help reduce burden of meeting New Zealand's comprehensive GHG emissions reduction targets. This suggests that while there is a potentially a strong trade-off between water quantity and water quality in the Hurunui region, imposing the right policy levers could significantly reduce some of the environmental impacts from an expected increase in land-use intensity without placing a large economic or regulatory burden on its landowners.

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TABLES

Table 1. Key Components of NZ-FARM, Hurunui Catchment, Canterbury, New Zealand

Region	Soil Type	Land Type	Enterprise	Irrigation Scheme	Fertilizer Regime	Mitigation Option	Variable Cost	Fixed Cost	Product Output	Environmental Indicators	Product Inputs
Plains Foothills Hills	Lismore Balmorals Hatfield Templeton	Pasture Cropland Horticulture Forest Scrub Dept of Conservation	Dairy - 3 Cows per ha, wintered on farm Dairy - 3 Cows per ha, wintered off farm Dairy - 3.5 Cows per ha, wintered on farm Dairy - 3.5 Cows per ha, wintered off farm Dairy - 4 Cows per ha, wintered on farm Dairy - 4 Cows per ha, wintered off farm Deer Pigs Mix of Sheep and Beef Grazing 100% Sheep Grazing	Irrigated Land Dry Land	100% rec. all nutrients 80% rec. N, 100% rec. all other nutrients 60% rec. N, 100% rec. all other nutrients 50% rec. N, 100% rec. all other nutrients No N, 100% rec. all other nutrients 0% rec. Lime, 100% rec. all other nutrients No fertilizer applied	Forest Carbon Sequestration DCDs Feed Pads	Beef stock replacement costs Sheep Stock Replacement cost Deer Stock replacement cost Dairy Stock replacement cost Pig stock replacement cost Wages - permanent Wages - casual Animal Health Dairy shed breeding Electricity Cartage Fertiliser Fertiliser application Fuel Shearing	Property taxes Insurance Land prep Tree planting Forest harvest Cultivation Forest management fee Herbicide application Fungicide application Pruning Thinning Harvest costs Harvest preparation DCD Application Feed pad construction	Milk solids Dairy calves Lambs Mutton Wool Cull cows Heifers Steers Bulls Deer: hinds Deer: stags Deer: velvet Pigs Berryfruit Grapes Wheat Barley Logs for pulp and paper Logs for Timber Other Misc.	N leached (kg N) P lost (kg P) Methane from animals (kg CO2e) N2O emissions – direct excreta and effluent (kg CO2e) N2O emissions – indirect excreta and effluent (kg CO2e) CO2 emissions - N fertiliser (kg CO2e) CO2 emissions – Lime (kg CO2e) N_2O emissions – direct and indirect N from fertiliser (kg CO2e) CO2 emissions – fuel (kg CO2e) CO2 emissions - electricity use (kg CO2e) Annual Forest C Sequestration (kg CO2e)	Dairy calves purchased Lambs purchased Rams purchased Ewes purchased Cows purchased Heifers purchased Steers purchased Bulls purchased Pigs purchased Dry matter Electricity used Fertiliser used - Urea Fertiliser used - Super Fertiliser used - Lime Fertiliser used - other Nutrients used -N

Region	Soil Type	Land Type	Enterprise	Irrigation Scheme	Fertilizer Regime	Mitigation Option	Variable Cost	Fixed Cost	Product Output	Environmental Indicators	Product Inputs
			100% Cattle Grazing Grapes Berry Fruit Wheat Barley Pine Radiata Plantations				Seeds Imported Feed costs - hay & silage Imported feed costs - crops Imported feed costs - grazing Imported feed costs - other Water charges Depreciation on capital Roads for forest plantations				Nutrients used -P,K,S Nutrients used -Lime Nutrients used -Other Fuel used - Petrol Fuel used - Diesel Irrigation rate Irrigation type Irrigation- number of days Seed used Supplementary feed bought - hay & silage Supplementary feed bought - crops Grazing Supplementary feed bought - other Harvest length

Table 2. Baseline Regional Output* for Hurunui Zones

Output	Plains	Foothills	Hills	Total
Milk Solids	18965.1	405.3	0.0	19370.4
Dairy Calves	1221.1	32.3	0.0	1253.4
Lambs	5061.2	3430.6	714.5	9206.3
Mutton	506.1	484.9	101.0	1092.1
Wool	922.6	519.6	108.0	1550.3
Cows	2671.2	1976.9	202.1	4850.1
Heifers	763.2	17467.3	1849.3	20079.8
Steers	9248.6	19407.5	2056.8	30712.9
Bulls	0.9	0.0	0.0	1.0
Deer Hinds	85.3	0.1	0.1	85.5
Deer Stags	58.8	0.1	0.1	59.0
Pigs	2609.5	43.0	0.0	2652.4
Berryfruit	44.1	0.0	0.0	44.1
Grapes	124.4	351.8	0.0	476.2
Wheat	4709.8	0.0	0.0	4709.8
Barley	31821.5	0.0	0.0	31821.5
Pulp Logs	38.9	6.2	0.0	45.1
Timber	155.5	24.7	0.1	180.3

*Agriculture products in tonnes, while forest products are in thousand m^3

Table 3. Baseline Land Use for Hurunui Zones (thousand ha)

Land Use	Plains	Foothills	Hills	Total	Percent
Forest	8.87	1.36	0.01	10.23	4%
Cropland	5.38	0.00	0.00	5.38	2%
Horticulture	0.01	0.03	0.00	0.04	0%
Pasture	60.38	55.40	28.79	144.57	56%
Scrub	0.93	7.13	6.00	14.05	5%
DOC Land	0.29	7.48	76.74	84.51	33%

Table 4. Baseline GHG Emissions for Hurunui Catchment (tCO_2e)

GHG Emissions	Plains	Foothills	Hills	Total	% Total
CH4 Enteric Fermentation	440.9	234.3	48.9	724.1	82.0%
CH4 Manure Management	9.2	2.9	0.2	12.2	1.4%
N2O Animal Waste Mgmt Systems	0.2	0.0	0.0	0.2	0.02%
N2O Grazing	69.4	36.5	7.4	113.3	12.8%
N2O Fertilizer	19.8	0.3	0.0	20.1	2.3%
CO2 Fuel	8.1	0.9	0.2	9.1	1.0%
CO2 Electricity	3.5	0.2	0.0	3.7	0.4%
Forest C Sequestration	-159.7	-63.9	-177.5	-401.2	-45.4%
Total Emissions	551.0	275.0	56.8	882.8	
Net Emissions	391.3	211.1	-120.8	481.7	

Figure 1. Structure of Nest for Allocation of Land to Land Use to Enterprise to Output in NZ-FARM

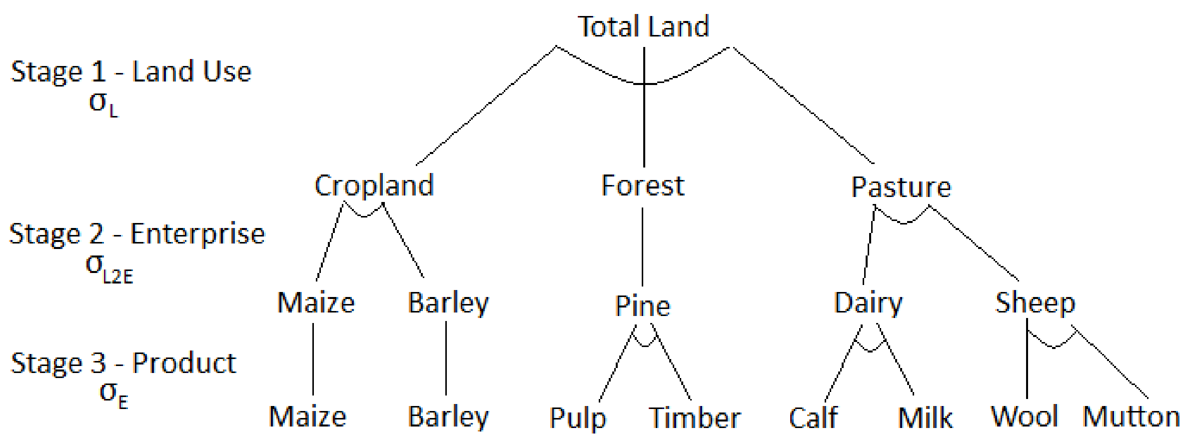

Figure 2. Hurunui Catchment, North Canterbury, New Zealand

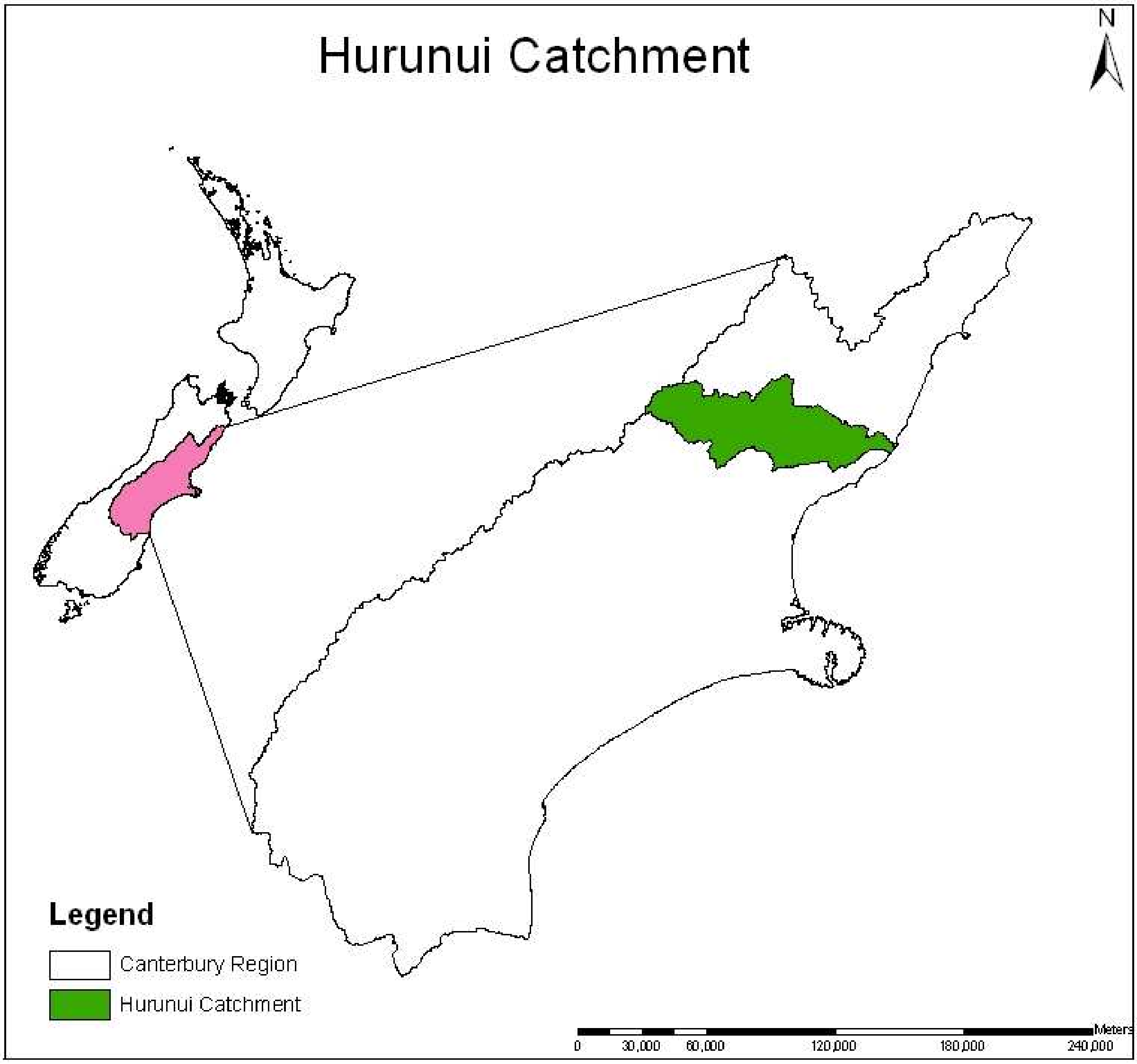

Figure 3. Distribution of Zones for Hurunui Catchment

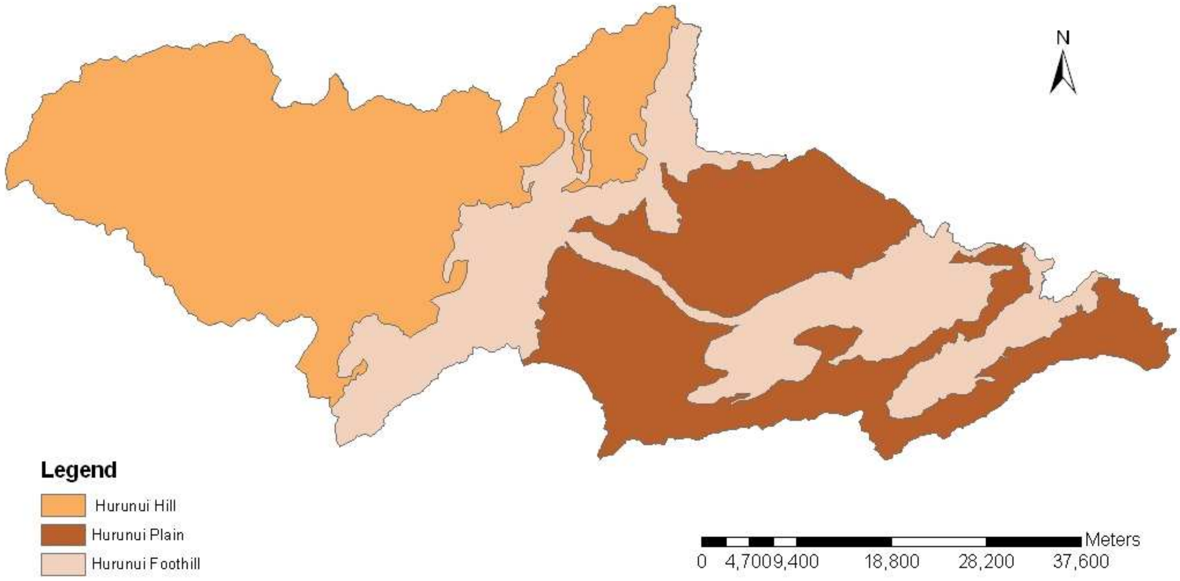

Figure 4. Baseline Enterprises and Water Storage Proposal Sites for Hurunui Catchment

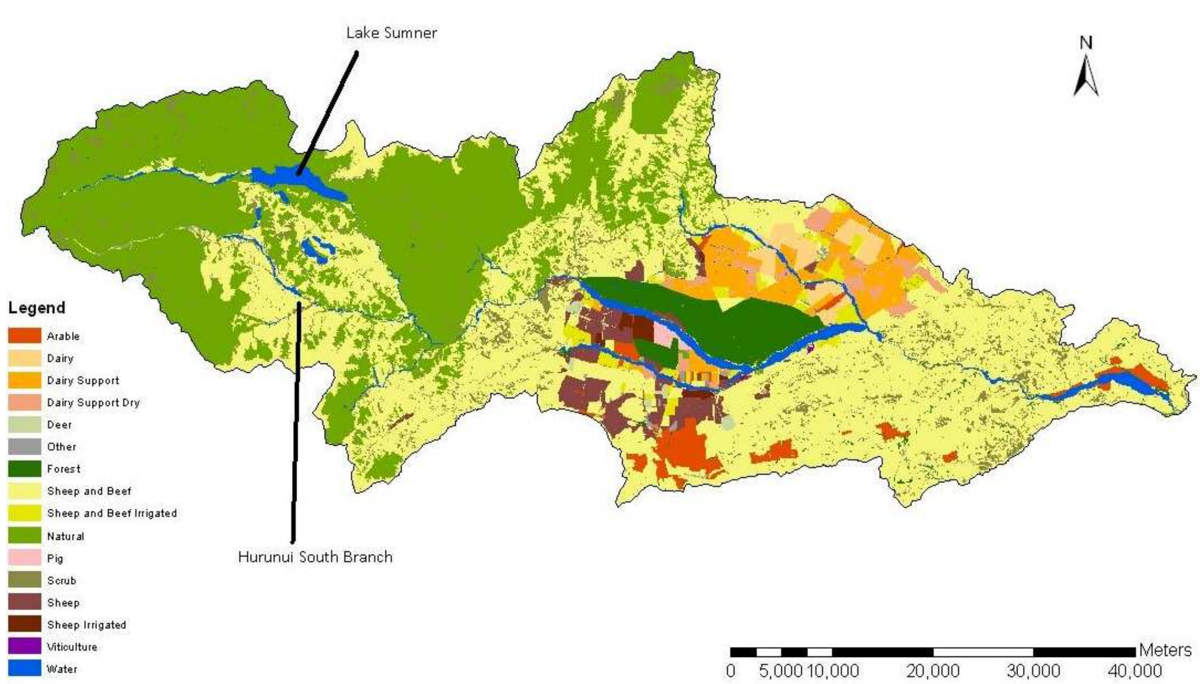

Figure 5. Regional Land Use for Hurunui Catchment, Baseline and Policy Scenarios

Figure 6. Regional Enterprise Area for Hurunui Catchment, Baseline and Policy Scenarios

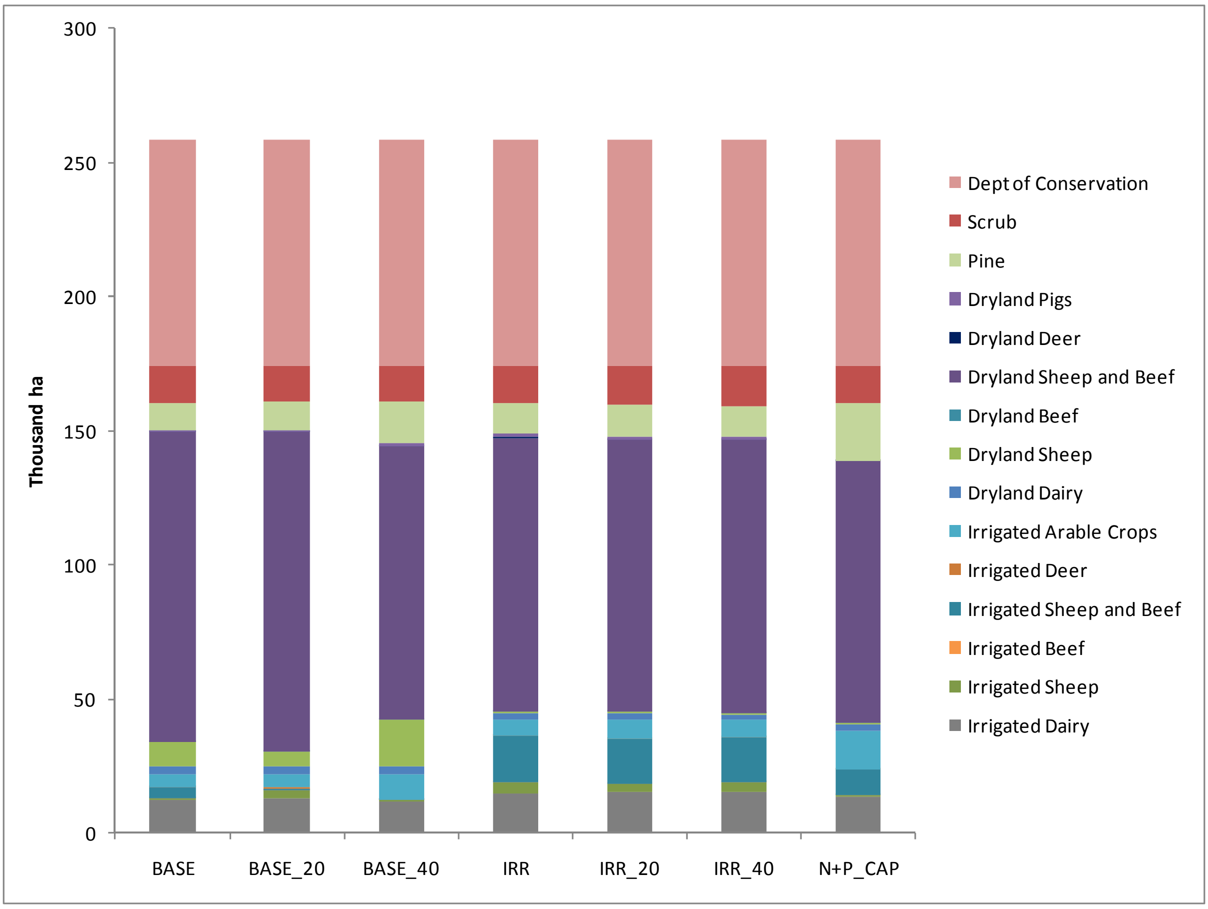

Figure 7. Percentage change from baseline, net catchment revenue and environmental outputs