Synergies between policy instruments for regulating interdependent pollutants: a numerical analysis of emissions trading schemes in New Zealand*

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Abstract

Agricultural production affects both nutrient and greenhouse gas emissions. Environmental policy designed to reduce one type of pollution may interact in positive or negative ways with efforts to reduce other types of pollution. In this paper we explore complementarity of abatement practices in the Lake Rotorua catchment in New Zealand (NZ) using an agro-environmental economic model, NManager. The application presents an ideal case study since the local government is considering the implementation of a nutrient trading scheme (NTS) to reduce nutrient discharges to the lake from non-point sources such as farmland. At the same time, the national government is reviewing whether to include greenhouse gas (GHG) emissions from the agricultural sector at a farm scale in a GHG emissions trading scheme (ETS). The abatement costs, the environmental impacts, and the distribution of costs and benefits under three different types of initial N permit allocation in the agricultural sector are evaluated under three policy scenarios: the inclusion of the agricultural sector in (1) the nutrient trading market only; (2) the NZ GHG emissions trading scheme (ETS) only; and (3) both the regional NTS and the NZ ETS concurrently. Results illustrate

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that (i) the total level of GHG mitigation is higher with the concurrent NTS and NZ ETS compared to when there is only a NZ ETS; (ii) the permit price of nutrient discharges decreases as the permit price of GHG emissions increases; and (iii) there are stark differences in land-use change under each policy scenario–the GHG ETS alone resulted in no land-use change, the NTS alone resulted in no remaining dairy, while the dual policy setting (GHG ETS and NTS) made dairy, a highly profitable but also N intensive farm activity, to be economically viable once again; suggesting that there could be gains from an additional regulation.

Keywords. Climate change, carbon markets, greenhouse gas, environmental markets, nutrient trading, interactions

1 Introduction

In this paper we investigate numerically the possible interactions between two pollution permit trading schemes designed to curb greenhouse gas (GHG) emissions and nutrient runoff in the Lake Rotorua catchment in New Zealand (NZ). Agricultural GHG emissions, such as methane (CH_4) and nitrous oxide (N_2O) emitted from livestock production, are the single largest component of NZ's emissions profile. NZ is the first country in the world to implement a GHG emissions trading scheme (ETS) that includes forestry as a sector, and the government will review whether to include agricultural GHG emissions in 2015. In addition, NZ has an existing nutrient trading scheme (NTS) to control for water quality in Lake Taupo; a similar system is being considered for adoption in the Lake Rotorua region. Hence, NZ provides an ideal context for the applied study of pollution control policies involving tradable pollution permits schemes for air and water pollution markets.

Agriculture is the third largest industry in the Lake Rotorua catchment after the tourism and forestry sector. It makes up 8.3% of the local economy and 45% of the land in the catchment (Environment Bay of Plenty 2009). Agricultural production has adverse environmental impacts including excess levels of nutrient (e.g. nitrogen (N) and phosphorous (P)) leaching. Most of the increase in nutrient leaching in the Lake Rotorua catchment has been attributed to the intensification of agricultural production since the 1960s, and this excess nutrient discharges to the lake have caused eutrophication and increased toxic algal blooms (Parliamentary Commissioner for the Environment 2006).

Water quality in Lake Rotorua is important because of the key role tourism plays in the regional economy, and the cultural value it holds for local Iwi, which is a local Maori tribal group (Lock and Kerr 2008). Significant reductions in emissions are required to meet environmental targets for both water quality and climate change mitigation. However, such reductions are costly. To meet these targets, farmers may need to forego profitable opportunities, make large capital investments, implement costly mitigation practices, reduce the intensity of their production, or change land use. It is desirable that these environmental targets be achieved in a cost effective (i.e. least cost) manner.

Local and national authorities are exploring the use of market-based instruments (e.g. a cap and trade program) to manage N leaching and GHG emissions. Under a tradable pollution permit scheme, individuals can generate N leaching as long as they hold enough permits to cover their discharges. The total number of these permits is capped by the regional council to ensure that the environmental quality target is met. Farmers who are able to reduce their discharges in a less costly manner than others are likely to choose a relatively high discharge abatement level and sell excess permits to others with higher abatement costs. In this way, a tradable pollution permit scheme gives farmers the incentive to abate pollution until their marginal cost of abatement is equal to the permit price of N leaching. In theory, this allows emission targets to be met at the least economic cost. An extensive literature in economics supports the use of market-based instruments in general and particularly in nutrient trading (Shortle and Horan 2008) and GHG emissions trading (Tietenberg 2006).

Many of the management practices farmers adopt to reduce nutrient runoff will also affect GHG emissions and vice versa. As such there can be positive or negative interactions between the two trading schemes (Kerr and Kennedy 2009). When an economic market has multiple imperfections such as multiple pollution externalities and imperfect markets, a first-best Pareto optimum is not necessarily achieved through the creation of pollution markets as a public policy instrument (Lipsey and Lancaster 1956; Laffont 1988). According to the theory of second best, under these circumstances, i.e. when there are multiple market failures, an intervention designed to correct for one market imperfection will rarely lead to a welfare maximizing outcome, and can sometimes even reduce overall welfare by further exacerbating the remaining distortions. Yeo et al. (2013) provide a theoretical investigation on how positive interactions, or complementarities, of two separate pollution permit schemes affect the levels of two linked pollutants (e.g. GHG emissions and N leaching).

In this paper, we demonstrate several key results from Yeo et al. (2013). For example, Yeo et al. (2013) find that under both an ETS for GHG emissions and a NTS for nutrient runoffs, each designed to control a different type of pollution, there is an inverse relationship between the permit price of one pollutant and the other. We provide a numerical analysis of such pollution policy interactions in the Lake Rotorua catchment in NZ using an adapted version of an agro-environmental economic model, NManager, initially developed by Anastasiadis et al. (2012). Using simulated farm data from Smeaton et al. (2011), we extend the NManager model to include responses to the price of GHG permits and GHG emissions. NManager is a partial equilibrium model, which integrates catchment level hydrology model and farm profit as determined by both land-use decisions and intensity of production. While there are other sources of N exports, in the NManager model only N from dairy and sheep/beef farming is considered manageable by farmers. N runoffs from other sources such as from urban land-use runoff, septic tanks, geothermal areas are considered fixed in this model, but in practice, initiatives have been launched by the Bay of Plenty Regional Council (BoPRC) to address all these other sources of N leaching to the catchment (Anastasiadis et al. 2012).

The regional council is considering the implementation a NTS to reduce nutrient discharges to Lake Rotorua from non-point sources, i.e. farmland, and the NZ government will review whether or not to include GHG emissions from the agricultural sector into the

GHG ETS. Numerical simulations from the NManager model, which is calibrated to the Rotorua catchment, supplement the theoretical analysis in Yeo et al. (2013). We model the abatement costs, the environmental impacts, and the distribution of costs and benefits of agricultural production under three policy scenarios: the inclusion of the agricultural sector at a farm scale in (1) the regional nutrient trading market only; (2) the NZ GHG ETS only; and (3) both the nutrient trading market and GHG ETS concurrently. We assess the cost savings from joint management of the pollutants relative to regulating them independently.

This paper has several findings. Starkly different land-use patterns emerge under each of the three policy scenarios, with changes wrought under a single policy reversing in part when both policies are in place. While the GHG ETS alone resulted in no land-use change, the NTS alone resulted in no remaining dairy, while the dual policy setting (GHG ETS and NTS) made dairy economically viable once again. We discuss how these dynamics are driven by permit price interactions. As suggested by the land-use patterns, the addition of a GHG ETS to a NTS can have unintended consequences within a sector, as N runoffs from dairy actually increase. The sector with the greatest percentage reduction in N runoffs depends on the policy setting: relatively N-intensive dairy responds greatest to the NTS, while sheep/beef responds greatest to the GHG ETS (with or without the NTS). As in the case of N runoffs, we see unintended consequences from adding a GHG ETS to a NTS in the form of increased emissions from dairy. The total cost of compliance actually falls for both sectors when the GHG ETS is added to the NTS, though as we discuss later, the two sectors achieve this in different ways. As expected, we find that farmers are best off under grandfathering and worst off under auctioning and vice versa for the permitting agency (regional council).

This paper consists of four sections: a very brief description of the theoretical model developed by Yeo et al. (2013); a summary of the NManager model; an explanation of how the different policy scenarios are calibrated to conduct the numerical simulations to extend the NManager model, which previously considered nutrient leaching alone (Anastasiadis et al. 2012); and results from the simulation model. We present the outcomes for N leaching, GHG emissions, land-use change, abatement costs, and costs and benefits at the aggregate level (i.e. for the whole Rotorua catchment) and at a disaggregated level (i.e. at the farm-level). We analyze the costs and benefits of the three above-mentioned policy scenarios under three different types of initial N permit allocation in the Lake Rotorua catchment, including auctioning, free allocation, and grandfathering. We show that this initial allocations has strong consequences for the distribution of effects on farmers and the regional council.

2 Nutrient trading scheme

In 2005, the Bay of Plenty Regional Council introduced Rule 11 to limit on-farm nutrient losses (i.e. N and P runoff permitted) out of concern with the environmental impact nutrient leaching has on Lake Rotorua (Environment Bay of Plenty 2009). The regional council's long-term goal is to restore the Lake to the state that it was in the 1960s. This would involve reducing the amount of N arriving at the lake (i.e. the N load) from its current level of 593 tonnes per year to 435 tonnes per year.

The amount of N runoff from land at any given time (i.e. the N exports) will be different from the N loads at the lake. In 2009, total N exports to the lake were estimated to be 771 tN/yr, with 73% of nutrient exports estimated to originate from rural land uses. This is larger than the actual direct N loading to the lake. Although some N will move quickly overland into streams and rivers and arrive at the lake within a matter of hours, other N export will leach into the groundwater table and over many years slowly arrive at the lake. The time these groundwater flows take to arrive at the lake depend on their location within the catchment, but can exceed one hundred years.

When designing regulation to meet a specific environmental target it is desirable that the policy is straightforward to administer, easy to comply with, and cost effective. Anastasiadis et al. (2012) use NManager to investigate the costs of six potential nutrient management schemes in the Rotorua catchment. These schemes include several command and control schemes which force farmers to either adopt best management practice, change land-use, or uniformly reduce their N runoff. They also consider two market based schemes: (1) an export trading scheme where farmers could trade permits for N discharges; and (2) a more complicated vintage trading scheme where farms trade permits based on their inter-temporal N loads reaching the lake.

Anastasiadis et al. (2012) report two key findings. First, the market based regulations considered are more cost effective than prescriptive command and control regulations (such as requiring farmers to adopt best management practice or uniform emission reductions). Second, there is little difference in terms of cost effectiveness in reaching the environmental target between the export trading scheme and the more complex vintage trading scheme. Anastasiadis et al. (2012) argue that because the difference between these two regulations is so small that it would be better to use the more parsimonious regulation, i.e. an export trading scheme. A limitation of the model in Anastasiadis et al. (2012) is that it assumes that all dairy and sheep/beef farms are homogeneous. This may potentially understate the gains from using a trading scheme since it means that there is no potential for trade between farms of the same land-use type that vary in abatement cost.

2.1 Greenhouse gas emissions trading scheme

New Zealand is the first country in the world to implement a comprehensive ETS which includes GHG emissions from the agricultural and forestry sectors. From 2015, processors of agricultural products will have to surrender emission permits to cover GHG obligations determined by emission factors meant to reflect the associated on-farm GHG emissions. Since the emissions factors are a function of on-farm practices but otherwise uniform they may not necessarily reflect actual on-farm GHG emissions. Farms have the incentive to minimize their obligations, rather than their actual emissions directly. The only way that farmers can currently reduce their associated emissions is by reducing their production intensity and fertilizer inputs, or by changing land-use (i.e. from dairy to sheep/beef farming or from sheep/beef farming to forestry). If farmers choose to change from agricultural land use to forestry then they receive extra emissions permit (or credits) for carbon sequestration.

GHG emissions in the Rotorua catchment are small in the context of a national ETS, and total NZ GHG emissions are small in the context of global GHG emissions under the Kyoto protocol. In our analysis, we assume that the GHG price is exogenous to farms in this region, i.e. the farmers take the price as given. This is consistent with the assumption made in the model developed by Yeo et al. (2013). The NZ ETS has a short term carbon price cap of $25 (New Zealand Ministry for the Environment 2009). We further assume that this cap is binding and that there is a fixed constant carbon price of $25.

2.2 Mitigation options

There is a range of management practices available to farmers to reduce their GHG emissions and nutrient discharges (Smith et al. 2008; Smith and Olesen 2010). Some of these options may only reduce one form of emission but not the other. For example, installing feed pads will likely reduce nutrient runoff but may not reduce GHG emissions. While some other management practices will likely reduce both types of pollution. For example, reducing fertilizer application, adopting nitrogen inhibitors (such as DCD), reducing livestock intensity, and changing land-use from agricultural to forestry production will simultaneously reduce both GHG emissions and nutrient runoffs. Furthermore, there are also certain management practices, such as wetland and riparian restoration, which can reduce nutrient loading and increase carbon sequestration, but also increase the production of other GHGs (CH_4 and N_2O) (Compton et al. 2011).

In our model there are two types of actions that farmers can take to mitigate their nutrient runoffs and GHG emissions. First, they can change their management practices to reduce pollution given their current land-use. Second, farmers can change their land-use to a less pollution intensive production activity (e.g. switching from dairy to sheep/beef farming or from sheep/beef farming to forestry). Since there may be synergies from regulating the two pollutants simultaneously, the total cost of complying with both schemes simultaneously might be less than the cost of complying with each individually. In this paper we estimate the size of this cost savings.

3 Theoretical model

The numerical simulations in this paper are based on the model developed by Yeo et al. (2013). Yeo et al. (2013) consider a set of profit maximizing farmers $\mathbf{I} = \{1, ..., I\}$, each with a particular land quality x_i, who choose a land-use $j \in \mathbf{J}$, where $\mathbf{J} = \{D, SB, F\}$ is a set of land-use options (e.g. dairy (D), sheep/beef (SB), and forestry (F)), and a level of input $\theta_{i,j}$ (e.g. fertilizer). The input affects farm production, $Q_j(\theta_{i,j}, x_i)$ as well as two different types of pollution, i.e. N leaching, $N_j(\theta_{i,j})$, and GHG emissions, $GHG_j(\theta_{i,j})$. Either one or both types of pollution is/are subject to a permit scheme. The farmers face a set of prices $\mathbf{P}$=$\{P_j, P_\theta, P_N, P_G\}$ where P_j is the output price of the agricultural good, P_θ is the price of the input, P_N represents the permit price of N that the farmer has to pay if there is a nutrient trading scheme (NTS), and P_G is the GHG emissions permit price if the GHG ETS is in place. The permit price of GHG emissions is exogenous. However, the price of N pollution permits is determined endogenously. If the farmer decides to switch to forestry production, then he or she will also receive carbon credits at price P_G.

A particular farmer i chooses a level of input $\theta_{i,j}$ corresponding to land-use $j \in \mathbf{J}$ that maximizes profit:

$$\max_{\theta_{i,j}} \Pi_j(\theta_{i,j}, x_i, \mathbf{P}) = \max_{\theta_{i,j}} P_j Q_j(\theta_{i,j}, x_i) - P_\theta \theta_{i,j} - P_N N_j(\theta_{i,j}) - P_G GHG_j(\theta_{i,j}). \qquad (1)$$

Taking the first order condition of the profit maximization problem with respect to $\theta_{i,j}$, a farmer solves for the optimal level of input, $\theta_j^*(x_i, \mathbf{P})$. Substituting this into the profit function, the maximized profit for farmer i adopting land-use j is given by:

$$\Pi_j^*(x_i, \mathbf{P}) = \Pi_j(\theta_j^*(x_i, \mathbf{P}), x_i, \mathbf{P}). \tag{2}$$

Each farmer then chooses a type of land-use j that maximizes profit:

$$j_i^* = \arg\max_{j \in \mathbf{J}} \Pi_j^*(x_i, \mathbf{P}), \tag{3}$$

where θ_{i,j^*}^* represents the corresponding optimal level of input given the optimal type of land-use, j_i^*, that the farmer has chosen. When faced with either one of the tradable pollution permit schemes or both the NTS and GHG ETS, the farmer may choose to continue or change his or her land-use and/or adjust the level of input $\theta_{i,j}$.

Yeo et al. (2013) show that as expected farmers reduce input $\theta_{i,j}$ as P_G rises. If the pollution price rises sufficiently high, farmers may change land-use, from sheep/beef to forestry production for example. The switching points occur when the profit levels are equal between one land-use and the other. If $\omega_{j1,j2}(x_i, \mathbf{P})$ is the difference in the farmer's maximum profit between activity j_1 and activity j_2, $\omega_{j1,j2}(x_i, \mathbf{P}) = 0$ is a condition that identifies a set of price vectors $\mathbf{P}$ and values x_i for which the farmers are indifferent between activity j_1 and j_2. For example along $\omega_{D,SB}(x_i, \mathbf{P}) = 0$, we have that $\Pi_D^*(x_i, \mathbf{P}) = \Pi_{SB}^*(x_i, \mathbf{P})$. A similar condition holds for the switching point between SB and F.

We assume that there is a linear relationship between input use and nutrient leaching and GHG emissions. Since both N and GHG are linear functions in input use, there is also a linear relationship between N and GHG emissions. Following the notation in Yeo et al. (2013), GHG emissions as a function of N leaching can be expressed as:

$$GHG_j(N_j) = \eta_j N_j - \kappa_j \tag{4}$$

In the numerical analysis Section 4.2 below, the N leaching associated with different types of farm production activities are joined together to form a piece-wise linear function to describe the relationship between GHG emissions and N leaching. The coefficients can be estimated by regressing GHG emissions against N leaching.

While the input variable $\theta_{i,j}$ is the choice variable in the profit maximization problem, given the data we have for the numerical analysis in this paper, the profit maximization problem can be cast in terms of the pollution level $N_{i,j}$ instead of input level $\theta^*_{i,j}$.[1] In this case, we can also express the production function as a function of $N_{i,j}$ rather than $\theta_{i,j}$. Yeo et al. (2013) derive the properties of the model for the case of a quadratic production function:

$$Q^N_j(N_{i,j}, x_i) = x_i(\alpha_j N^2_{i,j} + \beta_j N_{i,j} + \gamma_j). \tag{5}$$

The profit function for farmer i for a type of land-use j, can be expressed as a function of the choice variable $N_{i,j}$:

$$\Pi^N_j(N_{i,j}, x_i, \mathbf{P}) = P_j Q^N_j(N_{i,j}, x_i) - (P_\theta \theta_j(N_{i,j}) + P_N N_{i,j} + P_G GHG_j(N_{i,j}). \tag{6}$$

Figure 1a shows a hypothetical example of how dairy, sheep/beef, and forestry profit might change for an individual farmer i as the permit price of N changes, keeping x_i, P_j, P_θ, and P_G constant. Figure 1b shows the corresponding hypothetical N leaching for the different farm production activities. While the profit functions are continuous in the input variables, there may be a discontinuity in N leaching when farmers change from one type of farm production activity to another.

4 The NManager model

In this paper we extend the NManager model developed by Anastasiadis et al. (2012) to include GHG emissions. NManager is a combined biophysical and economic model of N leaching from rural land use in the Lake Rotorua catchment. As applied by Anastasiadis

[1] Yeo et al. (2013) gives a more detailed explanation for why there is no loss of generality in either case since the assumption is that there is an injective (one-for-one) relationship between $N_{i,j}$ and $\theta_{i,j}$.

et al. (2012), the NManager model included three components: (1) a biophysical model, which simulates the environmental impacts of nutrient exports to Lake Rotorua; (2) an economic model of landowners' decisions on how to use and manage their land and the resulting nitrogen exports; and (3) a model of regulation and its impact on farmers' decisions and environmental outcomes. In this section we provide a brief summary of these original components of the NManager model and the ways in which it is extended in this paper.

4.1 A biophysical model of nutrient exports and GHG emissions

The data which informs the catchment model in NManager is derived from the Rotorua and Taupo Nutrient model (ROTAN), a catchment level hydrology model developed by NIWA in NZ (Rutherford et al. 2008). NManager distinguishes between N exports, defined as the amount of N discharged as a byproduct of production on a particular farm, and N loads, the amount of N entering the lake. The distinction between exports and loads must be made due to the presence of groundwater lags.

N reaches the lake via two pathways: (1) surface water flow, which travels quickly and reaches the lake within a year; and (2) the groundwater system, which travels slowly and may take up to 200 years before reaching the lake. Simulations from ROTAN suggest that around 47% of N exports reach the lake via surface water and the remainder via groundwater.

The amount of time that N exports take to reach the lake via groundwater depends on the geographic location of the exports within the catchment. Figure 2 shows the groundwater lag zones for the Lake Rotorua catchment. Results from ROTAN are used to categorize each parcel of land in the Lake Rotorua catchment into one of eight lag zones characterized by their mean residence time (MRT), which describes the average travel time of N to the lake via groundwater (Anastasiadis et al. 2012).

The proportion of N exports discharged in a particular place and time that have entered the groundwater by any given lag is modeled using a "unit response function" (URF). We use URFs developed by Anastasiadis et al. (2012) for each groundwater zone. The total load of a given export is the weighted sum of its surface water exports and its groundwater exports multiplied by the cumulative distribution of its URF at the given time (Anastasiadis et al. 2012). We assume that of the 756 tN/yr that are exported from the catchment, 278 tN/yr are unmanageable N exports. Unmanageable exports are those that cannot be controlled directly by land management, including leaching from the Rotorua Land Treatment System, septic tanks, the geothermal areas, and urban open spaces (Anastasiadis et al. 2012). Furthermore, we also assume that there is a minimum N leaching per hectare across the entire catchment (4 kg/ha/yr), which is also considered unmanageable (Anastasiadis et al. 2012).

4.2 Extending NManager to incorporate GHG emissions

We extend the agro-environmental economic model used in Anastasiadis et al. (2012) by incorporating the effects of introducing a permit price on GHG emissions, P_G. P_G is determined exogenously, and is assumed to be \$25/tonne of CO_{2e}. Similarly, we assume that if farmers switch to forestry production, they will receive a carbon credit payment of \$25/tonne of carbon sequestered. The permit price of N, P_N, however, is determined endogenously using the NManager model. The prevailing market price of N is the level that equalizes the total manageable N leaching from the agricultural sector and the cap of 435 tonnes of N/year set by the regional council, for the Lake Rotorua catchment.

Since a majority of the on-farm air and water pollution mitigation practices considered in the Smeaton et al. (2011) dataset involve changes in farm production intensity (e.g. reducing livestock density), which affects both N leaching and GHG emissions, we explicitly consider the relationship between GHG emissions and N leaching. We assume that there is a piecewise linear relationship between GHG emissions and N leaching. Dairy farming is the most nutrient intensive whereas forestry is the least nutrient intensive land-use considered in the lake Rotorua catchment. Based on the emissions and land-use data we estimate the thresholds of N leaching where the farmer switches from dairy to sheep/beef farming and to forestry production. This piecewise linear relationship between GHG emissions and N leaching, specified in kg/ha/yr, for dairy and sheep/beef is given by

$$GHG(N_{i,j}) = r_j N_{i,j} + s_j. \tag{7}$$

Estimates of the coefficient values r_j and s_j for $j \in \{D, SB\}$ reported in Table 1 are obtained by regressing GHG emissions and N leaching from dairy and sheep/beef on-farm management practices. The coefficient values r_{SBF} and s_{SBF} are approximated by the lowest point of GHG emissions from sheep/beef on-farm mitigation practices with carbon sequestration (GHG emissions of -7) due to forestry production. The estimated thresholds governing land-use are as follows: If N leaching is between 56 kg/ha/yr and 23.5 kg/ha/yr, then the farm is under dairy farm production. If it is between 11 and 23.5 kg/ha/yr, then it is under sheep/beef farm production. When N leaching is in between 4-11 kg/ha/yr then there is a mix of land-use that is either in sheep/beef farming or in forestry production. Lastly, if N leaching is 4kg/ha/year, then the farm under forestry production and is sequestering carbon, which is represented by a negative value of GHG emission (i.e. -7 tonnes of GHG/ha/year is sequestered). These thresholds specify whether the farmer is adopting on-farm management practices (e.g. by staying in dairy or sheep/beef farm production) or switching to forestry production completely.

4.3 An economic model of landowner decisions

Assuming a piecewise linear relationship between GHG emissions and N leaching, a farmer i under farm production activity j chooses an optimal level of $N_{i,j}$ that maximizes profit. Profit can be expressed as a piecewise linear function that is a specific conditional form of the expression in Equation 6.

$$\Pi_{i,j}^{N*} = P_j Q_j(N_{i,j}, x_i) - P_G GHG_j(N_{i,j}) - P_N N_{i,j} \tag{8}$$

where $GHG_j(N_{i,j})$ is given by Equation 7 and $Q_j(N_{i,j}, x_i)$ is given by Equation 5. While we have chosen to specify $N_{i,j}$ as the control variable in Equation (8), note that a choice of $N_{i,j}$ simultaneously determines GHGs and thus this objective function serves for all three policy scenarios.

Farmer profit curves are estimated from simulated data of the Waikato and Bay of Plenty monitored representative dairy and sheep/beef farms (Smeaton et al. 2011; Anastasiadis et al. 2012). This dataset includes the estimated profit level, GHG emissions, and N leaching that will result under different sets of farm management practices. The farm profit for forestry production is calculated based on a study by Levente (2012), where he proposed calculating an annuity value of carbon sequestration from forestry production based on the discounted value of carbon sequestered during the first ten years of a newly planted forest. This approach provides a more consistent comparison of the value of avoided GHG emissions and carbon sequestration over time (Levente 2012). In our analysis, we assume that forest production involves the maximum possible unmanageable N load of 4 kg/ha/year (Anastasiadis et al. 2012). We approximate the relationship between profit and N leaching as a quadratic function in the level of N by estimating the quadratic coefficients using regression techniques from this simulation dataset. The coefficient estimates are presented in Table 2 and fitted curves of a representative dairy and a sheep/beef profit function under BAU are depicted in Figure 3, and Figure 4.

4.4 Simulating environmental regulations

To implement the ETS, we assume that farmers take the price of GHG permits as given and that the GHG permit price is fixed at \$25/tonne CO_{2e}. In addition, we assume that farmers have to pay for all GHG emissions generated from on-farm management practices. To implement the NTS, we start with the regional council target load to the lake of 435 tonnes of N/year, and estimate that the requisite annual level of N allowances for the agricultural sector in the Rotorua catchment is 135 ton/ha/year, which is about a 74% reduction of nutrient leaching from the BAU scenario. We match the environmental target specified by the regional council, with a 100-year phase in period, during which the cap is progressively tightened.

5 Results

In response to different policy scenarios, landowners can make adjustments to land-use–the extensive margin and/or on-farm management options–the intensive margin. We discuss the environmental impacts, (i.e. land-use change, nutrient runoffs, and GHG emissions) of implementing the GHG ETS and NTS individually and when both tradable pollution permit schemes are in place. In our model, we allow for dairy and sheep/beef farmers to potentially shift into forestry production but we do not focus on farms that are already under forestry production before environmental regulations are in place because those farms do not change under these policies. Recall that we have assumed that there is no manageable load of N from forestry (with an unmanageable load of 4 kg/ha/yr). We begin the presentation of results with responses at the extensive margin of land-use change and at the intensive margin with changes in N runoff and GHG emissions. We then discuss the economic impacts (i.e. the compliance cost and profit loss) of these three different policy scenarios on dairy and sheep/beef farmers. Results presented for a particular farm type summarize outcomes for the farms which are of that type under BAU, whether or not some or all of the farms switch activity type due to a given policy scenario. Lastly, we discuss how the welfare effects on farmers and the regional council depend on how the N permits are initially allocated (i.e. auctioned, freely allocated, or grandfathered).

5.1 Land-use change

Figure 6 shows the land-use change under the three different policy scenarios. Starkly different land-use patterns emerge under each of the three policy scenarios, with changes wrought under a single policy reversing in part when both policies are in place. While the GHG ETS causes no land-use change, the NTS causes all dairy farmers to switch to another activity. This occurs because dairy farming is a relatively N intensive, and when P_N is high it is no longer profitable to stay as dairy farmers. The dual policy setting, however, encourages the re-emergence of dairy farmers and an exodus from sheep/beef farmers. Permit price interactions drive this dynamic: the addition of an ETS to the NTS drives down P_N, enhancing the relative returns of N-intensive sectors like dairy. Interestingly, 100% of sheep/beef farm is converted to forestry under the dual policy scenario and this is because sheep/beef farmers find it more profitable to be receiving carbon credits through forestry production than to stay as sheep/beef farmers under the prevailing prices P_N and P_G when both policies are in place. Outcomes for GHG and N emissions are presented in Tables 3 and 4. In these tables, we see that the NTS alone is more stringent than the GHG ETS alone. Specifically, the NTS alone leads to approximately 2.5-3 times greater reduction in both pollutants than the GHG ETS alone.

5.2 Nutrient runoffs

Table 3 summarize the key results for N leaching for dairy and sheep/beef farmers under the three policy scenarios. As suggested by the land-use patterns, the addition of a GHG ETS to a NTS can have unintended consequences within a sector as N runoffs from dairy actually increase. The sector with the greatest percentage reduction in N runoffs depends on the policy setting: relatively N-intensive dairy responds greatest to the NTS, while sheep/beef responds greatest to the dual policy setting, i.e. when both the GHG ETS and NTS are in place. When there is only a NTS, N runoffs are reduced by 85% for dairy compared to 54% for sheep/beef farmers. When both the GHG ETS and NTS are implemented, we see a 100% reduction in N from BAU levels by sheep/beef farmers as all sheep/beef farmers shift to forestry production, but N abatement from dairy farmers decreases from 85% to 58%. Under the modeling assumption that there exist complementarities in the mitigation options in reducing both N and GHG emissions, we show that even when N is not being regulated directly, i.e. when there is only a GHG ETS, N exports decreased by about 23% overall from BAU levels. Further, under a GHG ETS only policy scenario, sheep/beef farmers will reduce N more than dairy farmers. At the aggregate level, when there is a cap on N, N runoffs decrease by about 74% to reach the 36% of BAU exports. Though there are policy-driven differences in the *allocation* of N reduction, note that regardless of the policy the nutrient cap is still binding and aggregate N abatement (relative to BAU) is the same.

5.3 Greenhouse gas emissions

The GHG ETS alone led to less aggregate GHG abatement than under the NTS alone as well as under the dual policy. The impacts of the environmental regulation on dairy and sheep/beef GHG emissions are shown in Table 4. Since the percentage reduction of GHG emissions from BAU take into account carbon sequestration, the percentage reduction exceeds 100%. That results show that under an NTS only, GHG emissions will be reduced by 125% even when GHG emissions are not charged. GHG emissions will be reduced the most (155%) when a GHG ETS and a NTS are both in place. The significant reduction in GHG emissions from BAU can be explained by a significant shift in land-use from sheep/beef farming to forestry and the associated carbon sequestration from forestry production.

In contrast to N runoffs, the percentage reduction in GHG emissions for sheep/beef is the greatest compared to dairy farmers regardless of the policy setting. However, as in the case of N runoffs we see unintended consequences from adding a GHG ETS to a NTS in the form of increased GHG emissions from dairy farmers. This is because some dairy farmers now find it more profitable to stay as dairy farmers rather than changing to sheep/beef farming because P_N is lower when both tradable pollution permit schemes are in place. This is consistent with the result in the comparative static analysis of Yeo et al. (2013).

Figure 7 shows the total GHG pollution permits bought and carbon credits received in the Rotorua catchment. Under the dual policy scenario only dairy farmers are buying GHG permits. The decrease in P_N made it possible for dairy farmers to stay in business but the prevailing market price for both P_N and P_G caused 100% of sheep/beef farmers to shift to forestry production for carbon credits. Hence, there is a significant increase in the total level of carbon credit received under the combined NTS and ETS case.

5.4 Profit and the cost of compliance

The total cost of compliance actually falls for both sectors when the GHG ETS is added to the NTS. This reduction in compliance cost is achieved in different ways for the two types of farmers: dairy farmers take advantage of cheaper N permits to cut back on abatement while sheep/beef farmers enhance abatement (largely through switching to forestry) by taking advantage of carbon credits. Table 5 summarizes the production profit, profit, abatement cost, and compliance cost for dairy and sheep/beef farmers ($/ha/yr) under the three different policy scenarios. Recall that profit from Equation (6) is given by production profit ($P_j Q_{i,j}$), less the cost of permits and net of any carbon credit revenue. When farmers adjust farm production to reduce N runoffs for a given set of environmental regulation, the farmer reduces his/her production profit. The cost of compliance is calculated as the difference between profit under BAU and profit under regulation. Profit is lowest and cost of compliance is highest for both dairy and sheep/beef farmers when only the NTS is implemented. This is because N runoffs from agricultural production have to be reduced by close to 74% to meet the regional council's target load of 435 tonnes/year to Lake Rotorua. When both the GHG ETS and NTS are implemented, however, the profit levels increase and costs of compliance decrease for both dairy and sheep/beef farmers. The implementation of the GHG ETS decreases the permit costs that dairy farmers have to pay for N permits and make it possible for some of them to continue dairying. While 100% of sheep/beef farmers have shifted to forestry production under the GHG ETS and NTS policy scenario, their compliance cost is actually lower than their abatement cost. This is because sheep/beef farmers are receiving carbon credits from forestry production though they may lose production profit from shifting away from sheep/beef farming.

5.5 Distribution of costs and benefits

In this section, we examine the distribution of the costs and benefits under the above three policy scenarios for dairy farmers, sheep/beef farmers, and the regional council under three different N pollution permit allocation schemes: (1) N pollution permits are auctioned, i.e. the regional council owns the N permits and sells the N permits to the farmers; (2) N pollution permits are freely allocated, i.e. farmers receive the optimal level of N permits for free; and (3) grandfathering of N permits with buyback, i.e. farmers are granted N permits based on their respective BAU N leaching level and the regional council buys back the N permits up to the optimal level of N. Depending on how the N permits are allocated, the distribution of the costs and benefits of pollution abatement under each policy scenario will be quite different. As expected, farmers are best off under grandfathering and worst off under auctioning and vice versa for the permitting agency (i.e. the regional council). These rankings are maintained but weakened with the addition of a GHG ETS to a NTS since the cost of buying (and benefits of selling) N permits falls.

The net benefits for dairy farmers, sheep/beef farmers, and the regional council under different policy scenarios and initial N pollution permit allocation schemes described above are shown in Figure 8, Figure 9, and Figure 10. As shown in Figure 8, regardless of whether the N permits are auctioned or freely allocated, it costs the dairy farmers less when the GHG ETS is implemented alongside the NTS, since this decreases P_N. Conversely, if the N permits are grandfathered with buyback from the regional council, the dairy farmers will not benefit as much as when the ETS is implemented alongside the NTS. While P_N has gone down when there is also a price on GHG emissions, the demand for N permits also increases compared to when there is only a NTS, and this means that the regional council is buying less N permits back from the farmers who will then not benefit as much.

Similarly, the cost to sheep/beef farmers is significantly lower under the policy scenario when both nutrient and GHG emissions are regulated simultaneously and when the N permits are auctioned (Figure 9). When both N and GHG are being regulated, sheep/beef farmers move into forestry production completely and hence farm profit from sheep/beef farming decrease significantly. However, when the GHG ETS is in place, there is an opportunity for them to move to forestry production and hence a chance to receive carbon credits.

The regional council benefits less when N permits are auctioned and when there is both a GHG ETS and NTS in place compared to when there is only a NTS. This is again because P_N decreases and sheep/beef farmers have shifted to forestry production and are not demanding any N permits. However, if the N permits are grandfathered with buyback, then it would also cost the council less to buyback the N permits.

6 Conclusion

A NTS and a GHG ETS may become a reality for farmers in many parts of NZ. There is already a NTS in place in the Lake Taupo catchment and the local government is considering the implementation of a similar system in the Lake Rotorua catchment. From 2015, farmers could face a price for their GHG emissions under the NZ GHG ETS. This paper uses the agro-environmental economic model NManager to investigate the possible interactions between these two pollution permit schemes in the Lake Rotorua catchment. We examine how the profitability, the distribution of costs and benefits under various initial N permit allocation, and the environmental impacts (e.g. N leaching, GHG emissions, and land-use change) of dairy and sheep/beef farmers change under three different policy scenarios: the inclusion of agriculture in (1) the NZ GHG ETS only; (2) the nutrient trading market only; and (3) both the nutrient trading market and the GHG ETS concurrently.

There are several key findings from this research. The permit price interactions between P_G and P_N play a key role in driving the dynamics of land-use change, nutrient runoffs, GHG emissions, profit and compliance cost, as well as the distributional impacts to the different stakeholders in the catchment. First, while the GHG ETS alone resulted in no land-use change, the NTS alone forced 100% of dairy farmers to another farm production activity.

However, because of the reduction in P_N when both policies are in place, it is now viable for some dairy farmers maintain the same production activity but not for sheep/beef farmers. Second, the reduction in the price of P_N could have unintended consequences within a type of farming activity; we show that N runoffs from dairy farming under a dual policy setting actually increases compared to when there is only an NTS. Third, similar to the unintended consequence for nutrient runoffs, we see that GHG emissions for dairy farmers also increase under the dual policy setting, again to the reduction in P_N. However, overall GHG emissions decreases even more when both policies are in placed compared to when there is only a GHG ETS. Fourth, and perhaps of most interest to both policymakers and stakeholders, is that the total compliance costs actually fall for both dairy and sheep/beef farmers when the GHG ETS is implemented alongside the NTS.

The distribution of the costs and benefits of these two regulations on N leaching and GHG emissions depends on how the N permits will be allocated. In this paper, we considered three different N pollution permit allocation schemes: (1) N permits are auctioned; (2) N permits are freely allocated at optimal equilibrium levels; and (3) N permits are grandfathered with buyback up to the optimal level of N from the regional council. Farmers are best off under grandfathering but worst off under auctioning and vice versa for the regional council. These rankings hold true but are weakened when the GHG ETS is implemented alongside the NTS. Again, due to the reduction in P_N, farmers will receive less for their N permits when permits are grandfathered but at the same time it will also cost the regional councils less to buyback the permits when both tradable pollution permit schemes are in place.[2] When comparing between the NTS and the dual policy scenario, dairy farmers are better off when both tradable pollution permit schemes are in place either when N permits are auctioned or freely allocated. Interestingly, there is no change in the welfare of sheep/beef farmers when N permits are auctioned or freely allocated when both tradable pollution permit schemes

[2]Though we do not address the extension in this paper, under the dual policy scenario, many of the units of carbon credits received would be for reductions in GHG emissions that would have occurred anyway which could raise concerns of additionality.

are in place because they have shifted to forestry production and are not demanding any N permits.

We have assumed that there is a strong relationship between GHG emissions and N leaching mitigation practices in the agricultural sector. Many activities undertaken to abate emissions of one type of pollutant may have complementary effect on the emissions of another type. Hence, even if only one form of pollution (e.g. N leaching) is being regulated it will abate another form of pollution (e.g. GHG emissions) and help meet the environmental goal of another type of pollution. Given the interactions of the two tradable pollution permit schemes on the prices and levels of emissions, we have shown though numerical analysis that the total profit loss of having both tradable pollution permit schemes is less than the sum of the profit loss of having each pollution permit scheme individually. A better understanding of how these two environmental policies interact with each other will help policy-makers better evaluate and manage the tradeoffs and synergies in achieving various environmental objectives as well as the welfare effects different combinations of policies may have on stakeholders.

A Tables and figures

Table 1: **Estimated coefficient values for GHG emissions and N runoffs**

GHG emissions and N runoffs	N	Intercept	R^2	Number of obs
Dairy farm	0.1 (0.01)	4.0 (0.40)	0.8	19
Sheep/beef farm	0.2 (0.008)	1.4 (0.14)	0.9	13

Note: Standard errors are in parentheses.

Table 2: **Estimated profit function coefficients for dairy and sheep/beef farmers**

Profit function	N^2	N	Intercept	R^2	Number of obs
Dairy farm (BAU)	−0.4 (0.06)	46.5 (3.2)	−118.7 (41.6)	0.9	19
Sheep/beef farm (BAU)	−2.7 (0.32)	88.1 (6.9)	−238.1 (26.0)	0.9	13

Note: Standard errors are in parentheses.

Table 3: **Farm-level and aggregate N runoffs**

	BAU	GHG ETS only	NTS only	GHG ETS and NTS
Dairy farm				
N runoffs (kg/ha/yr)	60	49.3	9.2	25.0
% Reduction from BAU	0%	18%	85%	58%
Subtotal N runoffs (kg/yr)	321,796	264,325	49,406	134,075
Sheep/beef farm				
N runoffs (kg/ha/yr)	12	8.32	5.49	0
% Reduction from BAU	0%	31%	54%	100%
Subtotal N runoffs (kg)	184,502	127,859	84,379	0
Aggregate				
Total N runoffs (kg/yr)	506,299	392,184	133,785	134,075
% of N reduction from BAU	0%	23%	74%	74%

Note: The N results in this table pertain only to manageable N. Each hectare of land generates 4 kg/yr of unmanageable N in addition to the levels reported here.

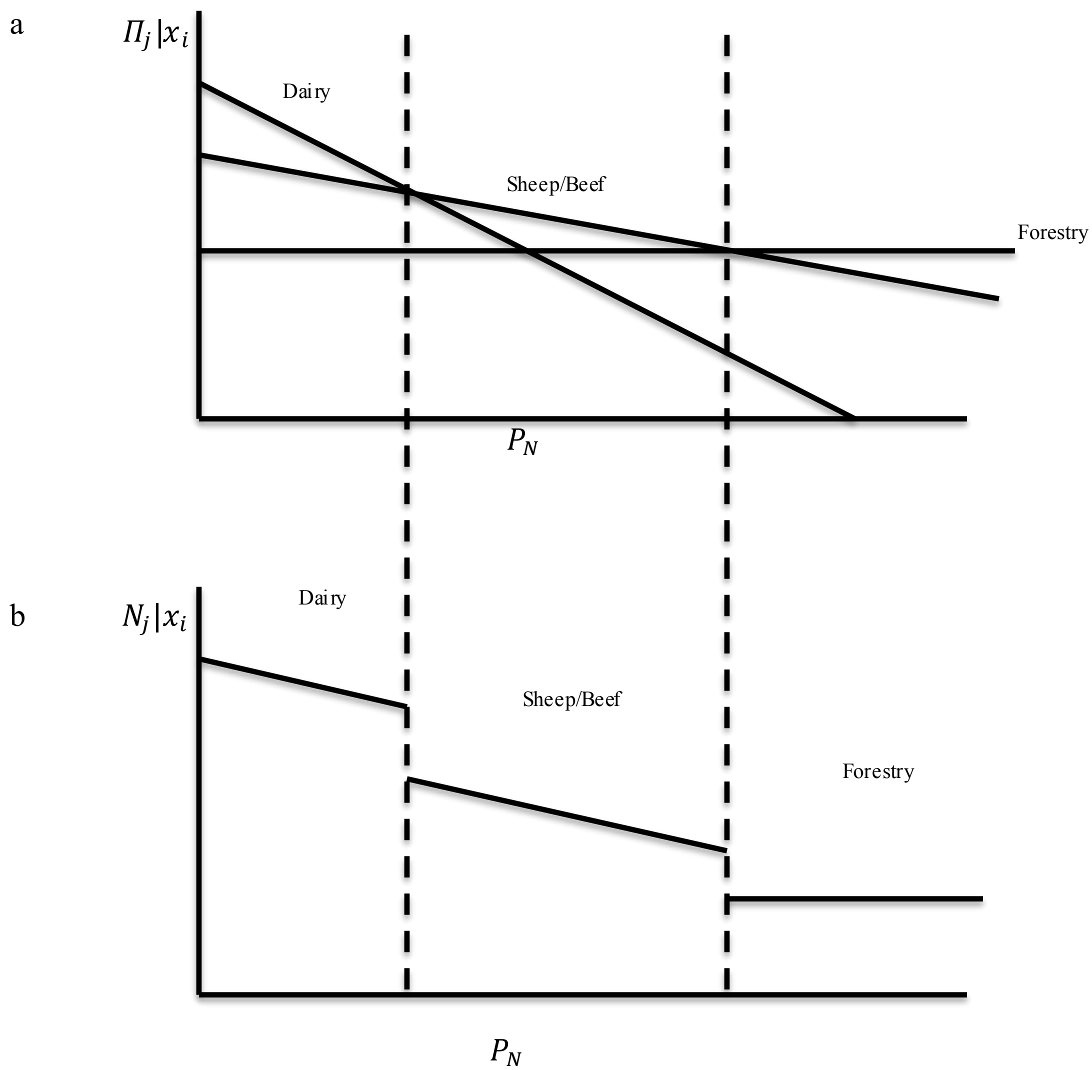
Table 4: **Farm-level and aggregate GHG emissions**

	BAU	GHG ETS only	NTS only	GHG ETS and NTS
Dairy farm				
GHG emissions (tonnes/ha/yr)	14.8	11.4	-1.1	6.0
% of Reduction from BAU	0%	23%	107%	60%
Subtotal GHG Emissions (tonnes/yr)	79,178	61,241	−5,834	31,963
Sheep/beef farm				
GHG emissions (tonnes/ha/yr)	3.77	0.59	−1.86	−7.00
% of Reduction from BAU	0%	84%	149%	286%
Subtotal GHG emissions (tonne/yr)	57,955	8,998	−28,581	−107,626
Aggregate				
Total GHG emissions (tonnes/yr)	137,133	70,239	-34,415	-75,663
% GHG reduction from BAU	0%	49%	125%	155%

Table 5: **Farm-level and aggregate profit levels and compliance cost**

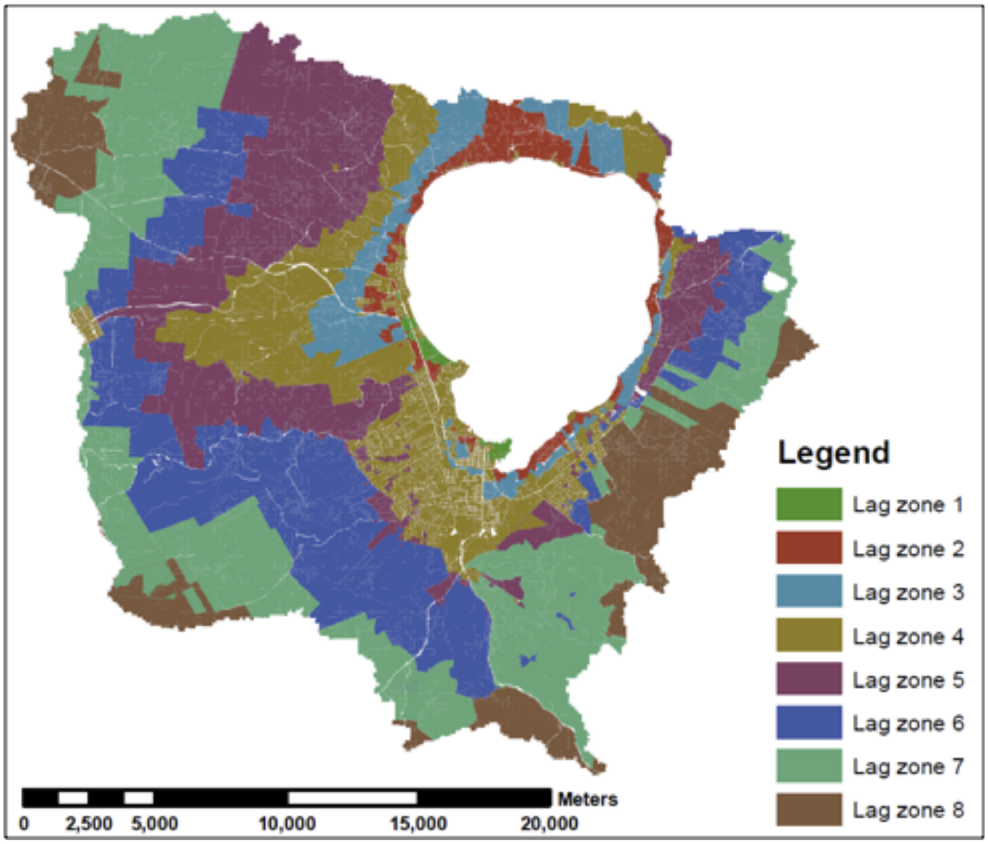
	BAU	GHG ETS only	NTS only	GHG ETS and NTS
Dairy farm				
Production profit ($/ha/yr)	$1,368	$1,326	$431	$920
Profit ($/ha/yr)	$1,368	$1,041	$92	$245
Abatement cost ($/ha/yr)	N/A	$41	$937	$448
Compliance cost($/ha/yr)	N/A	$327	$1276	$1123
Total compliance cost (millions $/yr)	N/A	$1.8	$6.8	$6.0
Sheep/beef farm				
Production profit ($/ha/yr)	$480	$437	$354	$71
Profit ($/ha/yr)	$480	$422	$152	$246
Abatement cost ($/ha/yr)	N/A	$42	$125	$409
Compliance cost($/ha/yr)	N/A	$57	$328	$234
Total compliance cost (millions $/yr)	N/A	$0.9	$5.0	$3.6
Aggregate				
Production profit (millions $/yr)	$N/A	$13.8	$7.8	$6.0
Profit (millions $/yr)	$N/A	$12.1	$2.8	$5.1
Abatement cost (millions $/yr)	N/A	$0.9	$7.0	$8.7
Total compliance cost (millions $/yr)	N/A	$2.6	$11.9	$9.6

Figure 1: **Example of profit and N leaching as a function of P_N under different farm production activities and P_N**



Note: The profit functions are likely to be non-linear but are drawn here in linear form for simplicity.

Figure 2: **NManager groundwater lag zones for Lake Rotorua in New Zealand**



Source: Anastasiadis et al. (2012)

Figure 3: **Farm-level profit as a function of N leaching for dairy producers**

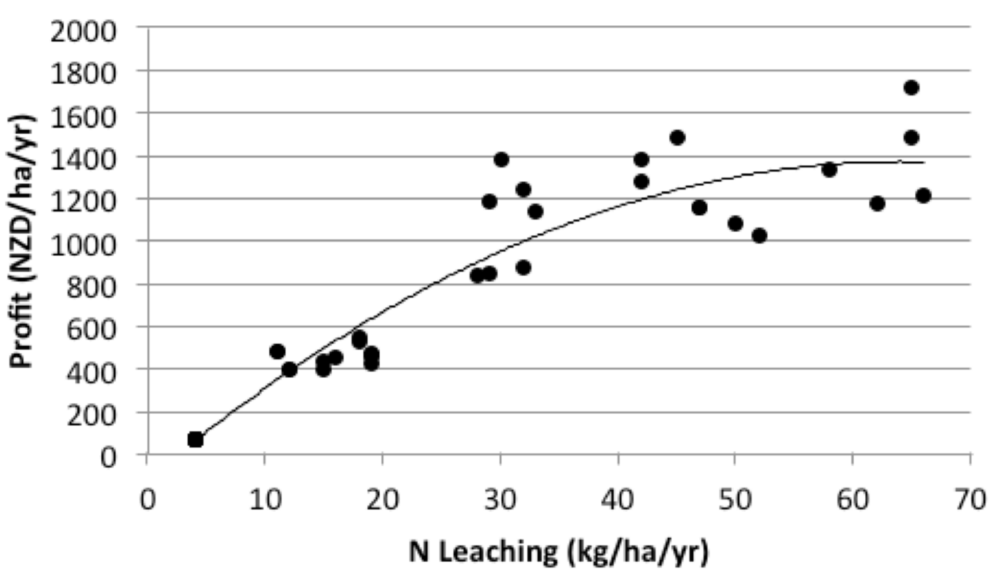


Figure 4: **Farm-level profit as a function of N leaching for sheep/beef producers**

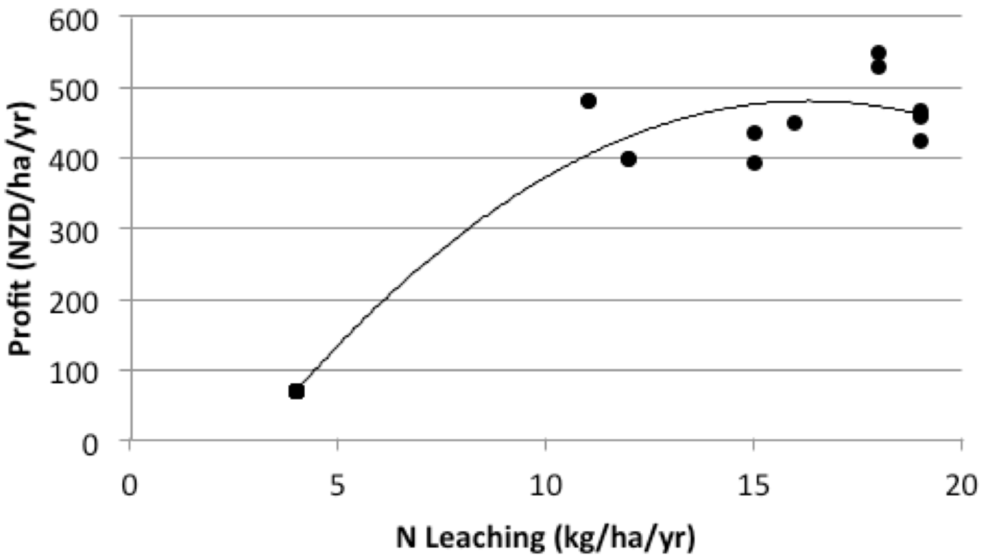


Figure 5: **GHG emissions as a piece-wise linear function of N leaching**

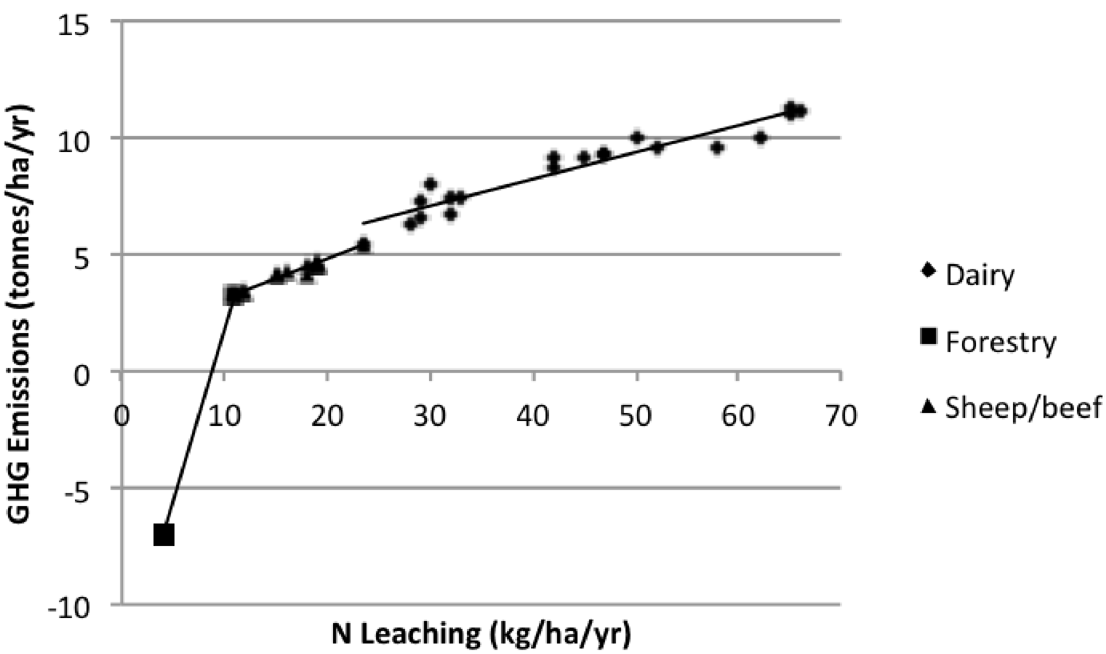


Figure 6: **Land-use change in the catchment under different policy scenarios**

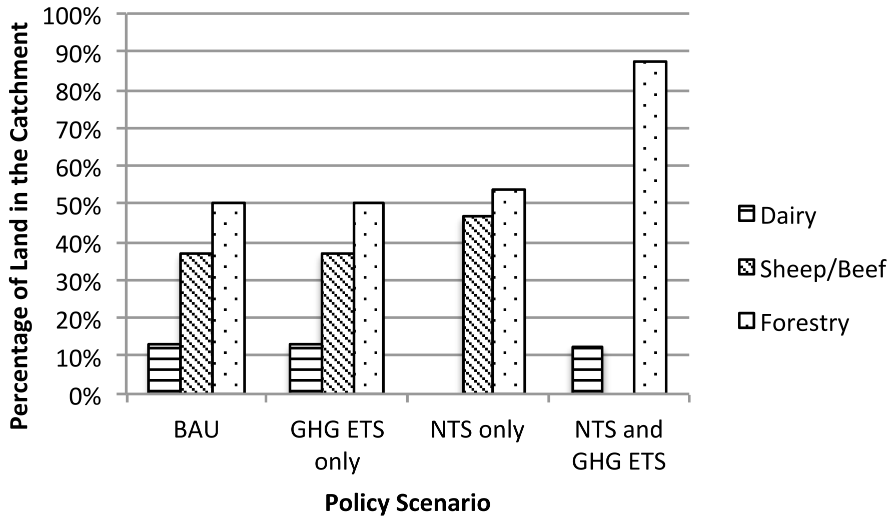


Figure 7: **The value of GHG emissions permits bought and carbon credits received from the international carbon market**

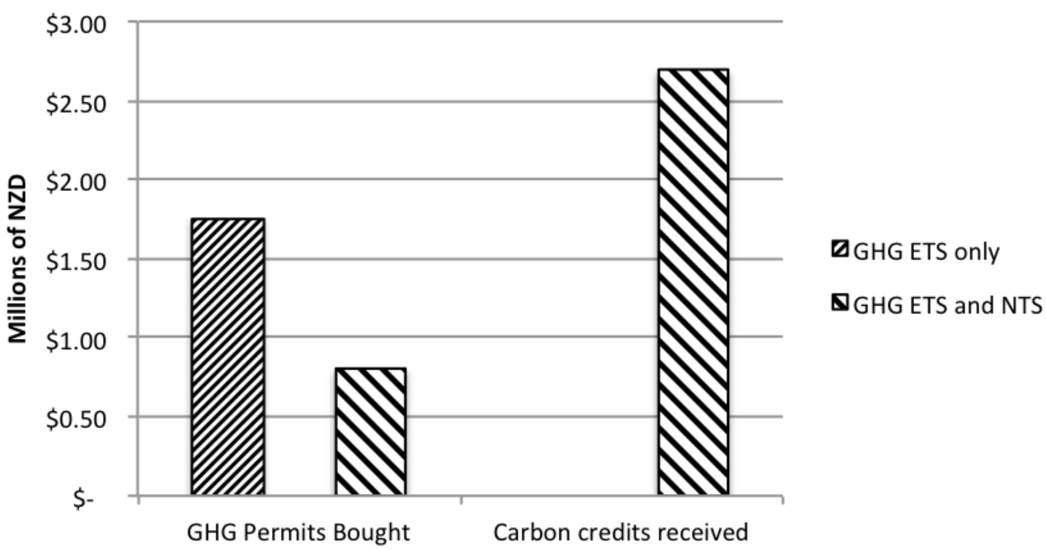
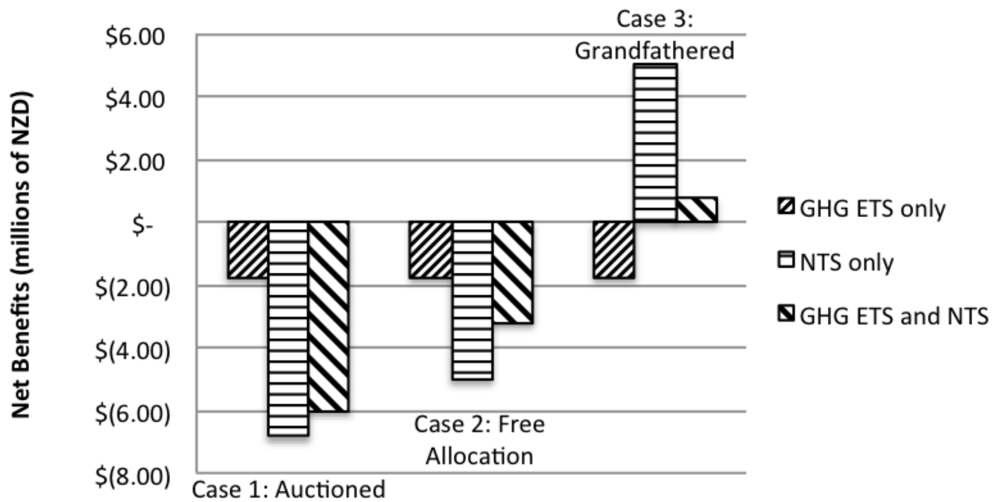
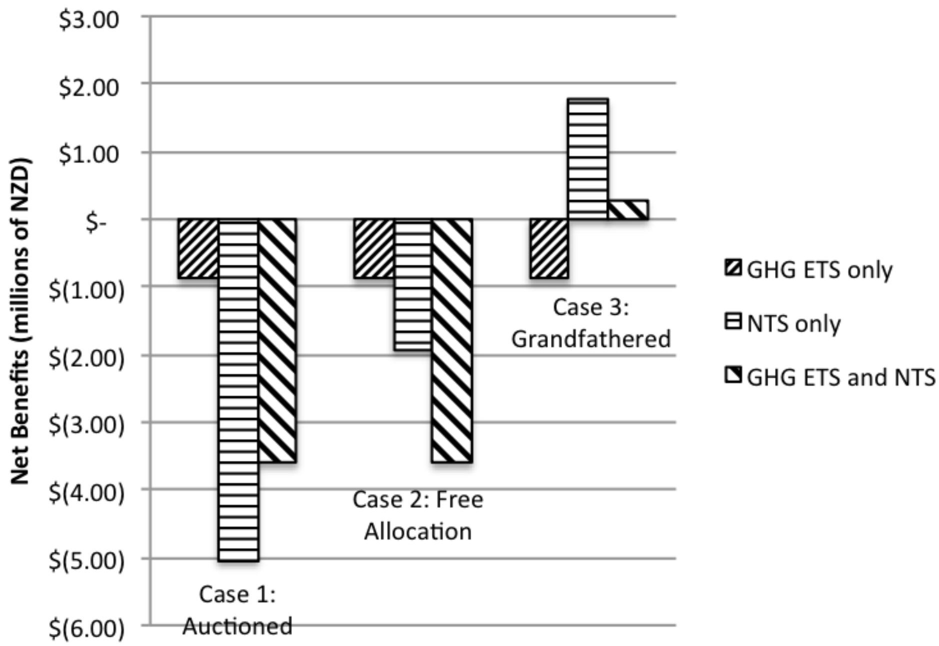


Figure 8: **Aggregate net benefits to dairy farmers under different N permit allocation approaches**



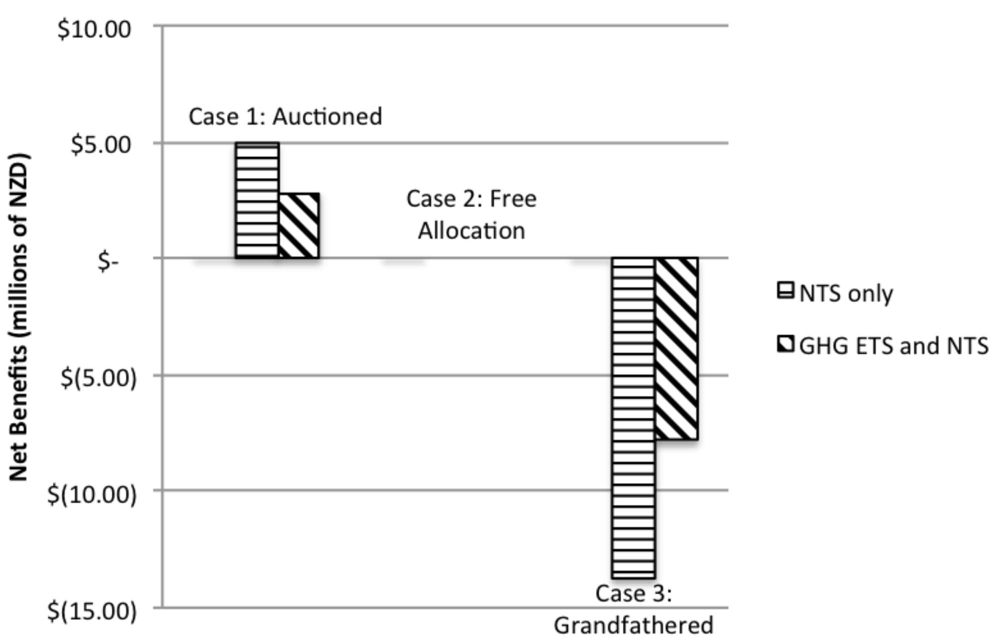
Note that net benefits here can also be defined as the negative of compliance costs for the farmers, where compliance cost is calculated as the difference between profit under BAU and profit under regulation.

Figure 9: **Aggregate net benefits to sheep/beef farmers under different N permit allocation approaches**



Note that net benefits here can also be defined as the negative of compliance costs for the farmers, where compliance cost is calculated as the difference between profit under BAU and profit under regulation.

Figure 10: **Aggregate net benefits to regional council under different N permit allocation approaches**



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