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# Synergies between Nutrient Trading Scheme and the New Zealand Greenhouse Gas (GHG) Emissions Trading Scheme (ETS) in the Lake Rotorua Catchment

**Boon-Ling Yeo[1], Simon Anastasiadis[2], Suzi Kerr[2], & Oliver Browne[2]**
[1]University of California
[2]Motu Economic and Public Policy Research

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**Author contact details**
Boon-Ling Yeo
University of California, Davis
blyeo@ucdavis.edu

Simon Anastasiadis
Motu Economic and Public Policy Research
simon.anastasiadis@motu.org.nz

Suzi Kerr
Motu Economic and Public Policy Research
suzi.kerr@motu.org.nz

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**Motu Economic and Public Policy Research**
PO Box 24390
Wellington
New Zealand

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

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## Abstract

The intensity of agricultural production affects both nutrient and greenhouse gas emissions. Environmental policy designed to reduce one type of pollution may have complementary effects on the other type. This paper explores this issue in the Lake Rotorua catchment in New Zealand using an agro-environmental economic model, NManager. The Regional Council is planning to implement a nutrient trading scheme (NTS) to reduce nutrient discharges to the lake, especially from non-point sources such as farmland, while at the same time the NZ government is planning the agricultural sector into the GHG emissions trading scheme (ETS). We model the abatement costs, potential level of total cost savings; and environmental impacts of agricultural production under three policy scenarios: the inclusion of agricultural in (1) the nutrient trading market only; (2) the NZ GHG emissions trading scheme (ETS) only; and (3) both the nutrient trading market and the NZ ETS concurrently. We find both analytically and numerically that (i) the total level of GHG mitigation is higher when there exist both the NTS and NZ ETS compared to when there is only a NZ ETS; (ii) the permit price of nutrient discharges is inversely related to the permit price of GHG emissions; and (iii) the total economic profit loss from pollution abatement is lower when GHG emissions and nutrient discharges are managed concurrently compared to the sum of the economic profit loss from regulating GHG emissions and nutrient discharges separately.



## JEL codes

Type codes

## Keywords

Greenhouse gas, environmental markets, nutrient trading, emissions, interactions

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**PART I**

## 1. Introduction

The agricultural sector has been identified as the largest source of nitrogen (N) pollution, largely from intensification of meat production and increased use of synthetic N fertilizer (Vitousek 1994). Intensive agricultural production affects both nutrient discharges, particularly through the elevation of N and phosphorus levels, as well as greenhouse gas (GHG) emissions. According to the IPCC, the agricultural and forestry sectors combined are seen as the most important sectors in contributing to climate change mitigation (Trumper 2009). Based on an analysis conducted by Niles et. al. (2002), changes in the use and management of agricultural and forest lands in 48 major tropical and subtropical developing countries covering more than 50 million hectares of land over the next 10 years have the potential of reducing atmospheric carbon by about 2.3 billion tonnes.

Efforts to control air and water pollution through market-based mechanisms (e.g. tradable pollution permits) often treat these two pollutants separately. However, given the complementarity of some mitigation techniques in reducing both N and GHG emissions, the abatement costs of nutrient runoffs and greenhouse gas (GHG) emissions can be interdependent. Investigating how the interaction of two separate tradable pollution permit schemes affects the level of two different but related kinds of pollution is an important area of research because the environmental impacts to each regulation can be quite different depending on what other regulation is already in place. In addition, the distribution of the costs and benefits to the various stakeholders will also be different depending on what combination of policies is implemented.

A few studies have considered the multi-pollutant problem. Ungern-Sternberg (1987) examines the different types of pollutants that lead to a dying forest and argues that cost is an important consideration in formulating the different combination of pollutants to reduce. Adopting a similar approach to Ungern-Sternberg (1987), Michaelis (1992) argues that it may be less costly to reduce the emissions of different GHGs by translating them in terms of the prevented global warming potential rather than to focus on curbing $CO_2$ alone. In a policy environment were such substitutability between GHG is possible, his research asks the question of how to pursue an efficient policy against global warming when there are multiple pollutants (e.g. $CO_2$, $N_2O$, $CH_4$) contributing to a single consequence. He developed relative charge rates for the different GHGs compared to the one for $CO_2$ alone. While Ungern-Sternberg (1987) and Michaelis (1992) focus on multiple sources of pollution as well as pollutants leading to a single consequence, this paper is focusing on a single source of pollution that leads to two negative consequences. This paper is a special case of Yeo and Lin (unpublished Mimeo), which considers different forms of N pollution having multiple consequences including both negative and positive ones.

This paper investigates the possible synergies between two pollution permit trading schemes designed to curb GHG emissions and nutrient runoff in the Lake Rotorua catchment in New Zealand (NZ). Agricultural GHG emissions are the single largest component of NZ's emissions profile and NZ has obligations to reduce GHG emissions under the Kyoto protocol. GHGs such as methane ($CH_4$) and nitrous oxide ($N_2O$), emitted from livestock production contribute to global warming (IPCC, 2007). NZ is the first country in the world to implement a nationwide GHG Emissions Trading Scheme (ETS) that includes forestry, and it will be extended to include agricultural GHG emissions in 2015. In addition, NZ has an existing nutrient trading scheme to control for water quality in Lake Taupo, which is being considered for Lake Rotorua. 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). However, agricultural production has adverse environmental impacts. Excess levels of nutrient (e.g. nitrogen (N) and phosphorous (P)) discharges to the lake have caused eutrophication, increased harmful toxic algal blooms, and thus contributed to a decline in water quality (Parliamentary Commissioner for the Environment, 2006). Most of the increase in nutrient runoff has been attributed to the intensification of agricultural production since the 1960's (Parliamentary Commissioner for the Environment: Te Kaitiaki Taiao a Whare Paremata, 2006).

High water quality in Lake Rotorua is important because of the key role tourism plays in the Rotorua's economy, and the cultural value it holds for local Iwi (Lock and Kerr, 2008b). Significant reductions in emissions are required to meet environmental targets for both water quality and global warming potential. 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 can 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 these pollutants. Under a pollution permit scheme, individuals can generate pollution 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 is met. Polluters who are able to reduce their discharges in a more cost effective manner than others will choose to reduce their discharges and sell excess permits to others who are unable to meet their obligations. In this way, a pollution permit scheme give individuals the incentive to abate pollution until their marginal cost of abatement is equal to the price of emissions. This allows emission targets to be met at least economic cost. There is a strong literature in economics that 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 will be interactions between the two trading schemes (Kerr and Kennedy, 2009). This paper provides a theoretical investigation of how the interactions of two separate pollution permit schemes affect the levels of two different but related pollutions (e.g. GHG emissions and N leaching). It explores this issue in the Lake Rotorua catchment in NZ using an updated version of an agro-environmental economic model, Nmanager, developedby Anastasiadis et al. (2011). The Regional Council is planning to implement a nutrient trading scheme to reduce nutrient discharges to the lake, especially from non-point sources from farmland, and the NZ government will be introducing a GHG ETS to include GHG emissions from agriculture. Numerical simulations from the NManager model, which is calibrated to the Rotorua catchment, supplement the theoretical analysis. We model the abatement costs, potential level of total cost savings; and environmental impacts of agricultural production under three policy scenarios: the inclusion of agricultural in (1) the nutrient trading market only; (2) the NZ GHG emissions trading scheme (ETS) only; and (3) both the nutrient trading market and GHG ETS concurrently. Using simulated farm data from Smeaton et al. (2011), this paper extends the NManager model to include responses to the price of GHG permits and GHG emissions.

This paper has several findings. First, this research suggests that the total level of GHG emissions within the catchment declines when a nutrient trading scheme is introduced alongside an existing GHG ETS. Second, the permit price of N leaching is inversely related to the permit price of GHG emissions. Third, the sensitivity of GHG emissions to the permit price of GHG is lower when both pollution trading schemes are in place. In other words, the demand for GHG emissions becomes less responsive to a change in the price of GHG permits when there is also a permit price for N leaching. Finally, the total economic profit loss from pollution abatement is lower when GHG emissions and nutrient discharges are managed concurrently compared to the sum of the economic profit loss from regulating GHG emissions and nutrient discharges separately.

Some of the nutrient and GHG mitigation practices can be complementary in the Lake Rotorua catchment. When the nutrient trading scheme is already in place, the addition of the GHG ETS lowers N permit prices and can benefit the Regional Council or some farmers who have to buy the N permits. The introduction of a GHG ETS also makes it possible for farmers to receive carbon credits from switching to forestry production and this is likely to alter land-use patterns. Hence, the inclusion of agricultural and forestry sectors into the GHG ETS may prove beneficial to some agricultural producers.

This paper is divided into two parts. Part one provides a theoretical investigation of the research question, deriving the theoretical model and comparative static results. Part two provies the numerical simulations, whicih supplement the theoretical analysis. It consists of threesections: 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 only considered nutrient leaching along (Anastasiadis et al. 2011); and results from the simulation model. We present the results of N leaching, GHG emissions, land-use change, abatement costs, and the distribution of costs and benefits in an aggregate level (i.e. for the whole Rotorua catchment) and at a disaggregated level (i.e. how each policy scenario affect dairy farmers, sheep/beef farmers, and forest producers). We analyze the distribution of 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 and show its impacts on the farmers as well as the Regional Council. Finally, a conclusion of this research analysis is offered.

### 1.1. Nutrient Trading Scheme

In 2005, the Bay of Plenty Regional Council introduced ‘Rule 11’ to reduce on-farm nutrient losses (i.e. N and P runoff permitted) based on 2001-2004 land-use patterns out of concern with the environmental impact nutrient leaching has on Lake Rotorua. The Regional Council’s long-term goal is to restore the Lake to the state it was in in the 1960s. This would involve reducing the amount of N arriving at the Lake (i.e. the nitrogen load) from its current level of 593 tonnes per year to 445 tonnes per year.

The amount of N runoff from land at any given time (i.e. the nitrogen exports) will be different to the N loads. In 2009, total N exports 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 N loads. 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 leach into 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.

Further restricting all landowners’ discharges is unlikely to be the most efficient way to achieve further reductions in N runoff since it may be more costly for some individuals to meet the new target than others. A nutrient trading scheme is being considered in the Lake Rotorua catchment as a more efficient alternative to a tighter 'Rule 11'. Lock and Kerr (2008a) give an overview of what such a trading scheme would look like.

When designing regulation to meet a specific environmental target it is important that it is both straightforward to administer or comply with and can achieve the regulatory target at least cost. Anastasiadis et al. (2011) 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 farms to either adopt best manamagenent 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 for their inter-temporal N loads reaching the lake.

Anastasiadis et al. (2011) report two key findings: First, market based regulations outperform more prescriptive command and control regulations (such as requiring farmers to adopt best management practice or uniform emission reductions). Second, there is little difference between the export trading scheme and the more complex vintage trading scheme. Anastasiadis et al. (2011) 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. Implementing the more complex vintage trading scheme may impose greater cognitive costs on its participants, be less transparent or may otherwise be less likely to achieve its intended outcome.

A weakness with the model in Anastasiadis et al. (2011) 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 relatively more or less efficient farms of the same land-use type.

### 1.2. Greenhouse Gas Emissions (GHG) Emissions Trading Scheme (ETS)

NZ is the first country in the world to implement a nationwide GHG Emissions Trading Scheme (ETS) that includes forestry and will later include agricultural emissions as well (Newell et al. 2012). From 2015, processors of agricultural product will have to surrender emissions units to cover their GHG obligations. These obligations are currently determined by emission factors based on production intensity and don't necessarily correspond to the actual on farm GHG emissions. Farms have the incentive to minimise only their obligations rather than their actual emissions. The only way that farmers can currently reduce their emissions factors is by reducing their production intensity and fertiliser 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 units for carbon sequestration.

GHG emissions in the Rotorua catchment are small in the context of New Zealand's ETS, and total New Zealand's GHG emissions are small in the context of global GHG emissions under the Kyoto protocol. In our analysis, we assume that GHG prices are exogenous to farms in this region, i.e. the farmers take the price as given. The New Zealand ETS has a short-term carbon price cap of $25. We further assume that this cap is binding and that there is a fixed constant carbon price of $25.

### 1.3. Mitigation options

There are several actions that farmers can take to mitigate their nitrogen leaching and GHG emissions. First, they can change their management practices to minimise their pollution given their current stock intensity and land use. Second, they can reduce the density of the livestock on their land in order to reduce their pollution. Finally, farmers can change their land use to a less pollution intensive production (e.g. switching from dairy to sheep/beef farming or from sheep/beef farming to forestry).

There are a range of management practices available to farmers to reduce their GHG emissions and nutrient discharges. Some of these options may only reduce one form of emission but not the other, while some other management practices will likely reduce both. For example, installing feed pads will likely reduce nutrient runoff but may not reduce GHG emissions. While, reduced fertilizer application, nitrogen inhibitors (such as DCD), reducing livestock intensity, and changing landuse from agricultural to forestry production will simultaneously reduce both GHG emissions and nutrient runoffs.

Many management practices that farmers adopt can reduce both GHG emissions and nutrient runoffs. Hence, there may be synergies from regulating the two pollutants simultaneously. The total cost of complying with both schemes simultaneously might be less than the sum of the cost of complying with each individually. This paper tries to estimate the size of this cost savings.

# 2. Theoretical Model

## 2.1. A Simple Model

Let $j = D, SB, f$ be a type of production activity (e.g. dairy (D), sheep/beef (SB), and forestry (f)). Faced with the environmental regulations, and for a given level of exogenous variable, $x_i$ (e.g. land quality), that affects profitability, the dairy and sheep/beef farmer i chooses the level of input $\theta_{i,j}$ (e.g. fertilizer) that maximizes profit. This input, $\theta_{i,j}$, affects productivity, $Q_{i,j}(\theta_{i,j}, x_i)$, but it also generates surface water N pollution, $N_{i,j}(\theta_{i,j})$, and greenhouse gas (GHG) emissions, $GHG_{i,j}(\theta_{i,j})$. $P_N$ 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. We assume that farmers have to pay for the GHG emissions generated from on-farm management practices. In other words, any on-farm activity that generates any form of the following GHGs, e.g. methane ($CH_4$), carbon dioxide ($C0_2$), and nitrous oxide ($N_2O$), are all accounted for. Furthermore, if the farmer decides to switch to forestry production, the farmer will receive carbon credit for each ton of carbon sequestered.

We assume that the production function, $Q_{i,j}(\theta_{i,j}, x_i)$, is twice continuously differentiable, increasing and concave in, $\theta_{i,j}$, the abatement effort or input (i.e. $\frac{\partial Q_{i,j}}{\partial \theta_{i,j}} \geq 0$, $\frac{\partial^2 Q_{i,j}}{\partial \theta_j^2} \leq 0$). We also assume that $N_{i,j}(\theta_{i,j})$ and $GHG_{i,j}(\theta_{i,j})$ are increasing and convex in $\theta_{i,j}$ (i.e. $\frac{\partial N_{i,j}}{\partial \theta_{i,j}} > 0$ and $\frac{\partial^2 N_j}{\partial \theta_{i,j}^2} > 0$; $\frac{\partial GHG_j}{\partial \theta_{i,j}} > 0$ and $\frac{\partial^2 GHG_{i,j}}{\partial \theta_{i,j}^2} > 0$). For each farmer, i, and for each type of farm production activity, j, we define the profit function $\Pi_{i,j} = \Pi_{i,j}(\theta_{i,j}, x_i, P_j, P_\theta, P_N, P_G)$ as a function of the abatement effort or input ($\theta_{i,j}$), some exogenous variable ($x_i$) that affects profitability for each farmer, the produced output price, $P_j$, the price of the input (e.g. fertilizer), $P_\theta$, the price of the N permits, $P_N$, and the permit price of GHG emissions, $P_G$. For a given level of $x_i$, the farmer's decision to stay within dairy farming, switch to sheep/beef, or to forestry production, will depend on $P_N$ and $P_G$. For a given level of $x_i$ and each type of farm production activity, j, there will be an optimal level of $\theta_{i,j}^*$ that maximizes a farmer's profit, $\Pi_{i,j}$. In turn, there will be a type of farming production activity, j$^*$, that maximizes overall profitability. Let $\Pi_{i,j}^R$ be the profit of farmer i producing j under regulatory regime R. Let $R = \{NTS, ETS, NTS\_ETS\}$ be the type of environmental regulation in place. For example, R=NTS when $P_N > 0$; R=ETS when $P_G > 0$; and $R = NTS\_ETS$ when $P_N > 0$ and $P_G > 0$. For each j, farmer i solves for the optimal level of $\theta_{i,j}^*$ that maximizes the regulated profit $\Pi_{i,j}^R$.

$$\max_{\theta_{i,j}} \Pi_{i,j}(\theta_{i,j}, x_i, P_j, P_\theta, P_N, P_G) = Q_{i,j}(\theta_{i,j}, x_i)P_j - P_\theta \theta_{i,j} - P_N N_{i,j}(\theta_{i,j}) - P_G GHG_{i,j}(\theta_{i,j}) \qquad (1)$$

Solving $\frac{\partial \Pi_{i,j}^R}{\partial \theta_j} = 0$ we get a function $\theta_{i,j}^*(x_i, P_j, P_\theta, P_N, P_G)$ determining the optimal level of input $\theta_{i,j}$ that maximizes the regulated profit for a farmer i, under a particular type of farm production activity, j. The value of the profit when we have the optimal value of $\theta_{i,j}^*$ is:

$$\Pi_{i,j}^{*}(x_i, P_j, P_\theta, P_N, P_G) = \Pi_j(\theta_{i,j}^{*}(x_i, P_j, P_\theta, P_N, P_G), x_i, P_j, P_\theta, P_N, P_G) \quad (2)$$

The farmer then chooses a type of farm production activity $j^*$ that maximizes profit $\Pi_{i,j^*}^{*}(x_i, P_j, P_\theta, P_N, P_G)$:

$$j^* = * \, arg\,max_j\{\Pi_{i,D}^{*}(x_i, P_D, P_\theta, P_N, P_G), \Pi_{i,SB}^{*}(x_i, P_{SB}, P_\theta, P_N, P_G), \Pi_{i,f}^{*}(x_i, P_f, P_\theta, P_N, P_G)\} \quad (3)$$

Furthermore, $\theta_{i,j^*}^{*}$ is the corresponding optimal level of abatement effort or input given the optimal farm production activity, $j^*$, that the farmer has chosen. Equation (3) shows how the type of farm production activity undertaken depends on $x_i, P_N, P_G$.

Let $\omega_{j1,j2}(x_i, P_N, P_G)$ be the combinations of values where a farmer is just indifferent between activities $j_1, j_2$. Further, let $\Pi_{i,D}^{R*}$ be the profit function for dairy farmers and let $\Pi_{i,SB}^{R*}$ be the profit function for sheep/beef farmers, where the profit function is the same as what is described in Equation (1). The functions below give the value of $x_i$ (e.g. land quality) as a function of $P_N$ and $P_G$ where farmers are just indifferent between one type of farm production activity over another. Solving for the equilibrium levels below allows us to find the switching points between dairy to sheep/beef farming and from sheep/beef farming to forestry production. Figure 2 illustrates a hypothetical farm profit, i, for a particular type of farm production activity, j. Along $\omega_{D,SB}(x_i, P_N, P_G) = 0$,

$$(i)\Pi_{i,D}^{R^*}(x, P_D, P_\theta, P_N, P_G) = \Pi_{i,SB}^{R^*}(x, P_D, P_\theta, P_N, P_G) \quad (4)$$

And along $\omega_{SB,f}(x_i, P_N, P_G) = 0$,

$$(ii)\Pi_{i,SB}^{R^*}(x, P_D, P_\theta, P_N, P_G) = \Pi_{i,f}^{R^*}(x, P_D, P_\theta, P_N, P_G)$$

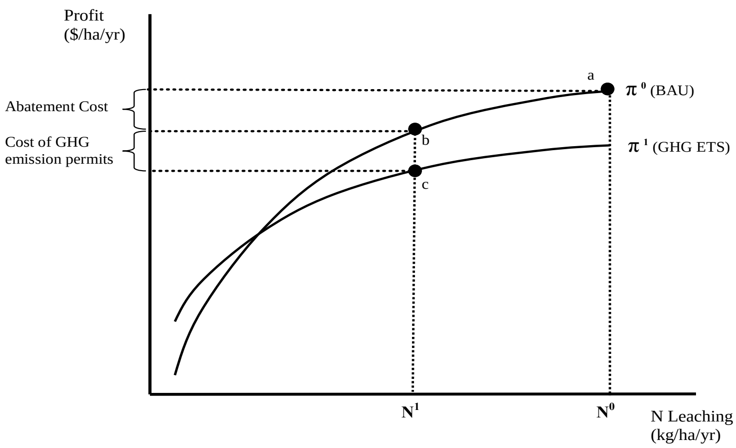
The absence of both an N target for Lake Rotorua and a GHG ETS implies that $P_N = 0$ and $P_G = 0$. With no regulation on either N or GHG emissions, the optimal level of $\theta_j^*$ is determined by maximizing the following unregulated, UR, profit function:

$$\Pi_{i,j}^{UR}(\theta_j, x, P_\theta, P_j) = \Pi_{i,j}(\theta_j, x, P_\theta, P_j, 0,0):$$

$$= Q_{i,j}(\theta_j, x)P_j - P_\theta\theta_j \quad (5)$$

The abatement cost for meeting a given environmental regulation is the difference between the maximum unregulated profit, $\Pi_{i,j}^{UR}$, and the maximum regulated profit, $\Pi_{i,j}^{R}$, under the different regulations. It is reasonable to assume that $\theta_{i,j}^{UR^*} > \theta_{i,j}^{R^*}$ for $P_N > 0$ and/or for $P_G > 0$, which is equivalent to $\frac{\partial \Pi_{i,j}}{\partial P_N}|_{P_N=0} < 0$. Figure 2 below gives an illustration of what the abatement cost of GHG emissions is when the GHG ETS is in place.

**Figure 1: Pollution Abatement Cost and Cost of Emissions Permits**




The permit price of GHG emissions is exogenous. This is an appropriate assumption in NZ since NZ is a price taker in the international carbon market. However, the price of N pollution permits is determined endogenously. Let $\overline{N}$ be the nutrient cap for Lake Rotorua and let $N^+$ be the sum of the individual N leaching quantities from the different farms in the Lake Rotorua catchment.

$$N^+ = \sum_{i=1}^{I} N^*_{i,j}(\theta^*_{i,j^*}(x_i, P_j, P_\theta, P_N, P_G)) \tag{6}$$

In equilibrium, when there is a pollution regulation on N, for a distribution of farmers, i, there exist a N permit price $P_N(\overline{N})$, such that:

$$\sum_{i=1}^{I} N^*_{i,j}(\theta^*_{i,j}(x_i, P_j, P_\theta, P_N(\overline{N}), P_G)) - \overline{N} \leq 0 \tag{7}$$

$$[\sum_{i=1}^{I} N^*_{i,j}(\theta^*_{i,j}(x_i, P_j, P_\theta, P_N(\overline{N}), P_G)) - \overline{N}]P_N(\overline{N}) = 0 \tag{8}$$

According to Equation (8), if not all permits are sold then $P_N = 0$. Otherwise, if $P_N > 0$ then all permits are sold.[1]

[1] The uniqueness of the price if not guaranteed. There exist a range of values where when the permit price $P_N$ increases just a little and it results in no changes in farmer's behavior. If $\frac{dN^+}{dP_N} < 0$ then there exists a unique solution.

# 3. Comparative Static Analysis

Assume that nutrient leaching and GHG emissions are linear functions of input use, $N_{i,j}(\theta_{i,j}) = \phi_{N1_{i,j}}\theta_{i,j} + \phi_{N2_{i,j}}$ and $GHG_{i,j}(\theta_{i,j}) = \phi_{G1_{i,j}}\theta_{i,j} + \phi_{G2_{i,j}}$. In other words, the fraction $\phi_{N1_{i,j}}$ of the input (e.g. fertilizer) is leached to the lake as water pollution and the fraction of the input $\phi_{G1_{i,j}}$ is being emited to the air as GHG emission. In the absence of fertilizer input (i.e. $\theta_{i,j} = 0$) a given farm production activity still produces some water pollution, $\phi_{N2_{i,j}}$, and air pollution, $\phi_{G2_{i,j}}$. Since an abatement effort will affect both N leaching and GHG emissions, there exists a positive linear relationship between the two. We can express GHG as a function of N leaching as:

$$GHG_{i,j}(N_{i,j}) = \frac{\phi_{G1_{i,j}}}{\phi_{N1_{i,j}}} N_{i,j} + [\phi_{G2_{i,j}} - \frac{\phi_{G1_{i,j}}}{\phi_{N1_{i,j}}}\phi_{N2_{i,j}}] \qquad (9)$$

For simplicity, we can express Equation (9) as:

$$GHG_{i,j}(N_{i,j}) = \frac{\phi_{G1_{i,j}}}{\phi_{N1_{i,j}}} N_{i,j} + K_{i,j} \qquad (10)$$

where $K_{i,j} = \phi_{G2_{i,j}} - \frac{\phi_{G1_{i,j}}}{\phi_{N1_{i,j}}}\phi_{N2_{i,j}}$. The coefficient can be estimated by regressing GHG emissions against N leaching. It means since N leaching is a function of $\theta_{i,j}$ and GHG emissions is also a function of $\theta_{i,j}$, the farm profit maximisation problem can be expressed by selecting the optimal level of N leaching.

Suppose that the production function $Q_{i,j}(\theta_{i,j}, x_i)$ takes a quadratic form and it can be expressed as a function quadratic in $N_{i,j}$. For each type of farm production activity, j, the farmer maximises the profit by selecting the optimal level of N leaching, $N^*_{i,j}$. In the completely general case, let's assume the production of the farm takes the following form: $(\alpha_j(x_i)N_j^2 + \beta_j(x_i)N_j + \gamma_j(x_i))P_j$ then the profit function for a particular type of production activity, j, can be expressed as:

$$\Pi_{i,j}(N_{i,j}, x_i, P_j, P_\theta, P_N, P_G) = (\alpha_j(x_i)N_{i,j}^2 + \beta_j(x_i)N_{i,j} + \gamma_j(x_i))P_j - (P_\theta(\frac{N_{i,j} - \phi_{N2_{i,j}}}{\phi_{N1_{i,j}}}) + P_N N_{i,j} + P_G GHG_{i,j}(N_{i,j})) \qquad (11)$$

where $\theta_{i,j} = \frac{N_{i,j} - \phi_{N2_{i,j}}}{\phi_{N1_{i,j}}}$, $\alpha_j$, $\beta_j$,and $\gamma_j$ are the coefficient values corresponding to different levels of dairy and sheep/beef farm production associated with the different combination N leaching. $\phi_{N1_{i,j}}$,$\phi_{N2_{i,j}}$, $\phi_{G1_{i,j}}$ and $\phi_{G2_{i,j}}$ are coefficient values estimated from the corresponding GHG emissions with each level of N leaching. Since N is increasing and linear in $\theta_{i,j}$ we assume that the farmer can choose the level of N leaching that maximizes profit. If the production $\left(\alpha_j(x_i)N_j^2 + \beta_j(x_i)N_j + \gamma_j(x_i)\right)P_j = x_i * (\alpha_j N_{i,j}^2 + \beta_j N_{i,j} + \gamma_{i,j})P_j$ , then the profit function may be expressed as follows:

$$\Pi_{i,j}\left(N_{i,j}, x_i, P_j, P_\theta, P_N, P_G\right) = x_i * (\alpha_j N_{i,j}^2 + \beta_j N_{i,j} + \gamma_{i,j})P_j - \left(P_\theta\left(\frac{N_{i,j} - \phi_{N2i,j}}{\phi_{N1i,j}}\right)\right) + P_N N_{i,j} + P_G\left(\frac{\phi_{G1i,j}}{\phi_{N1i,j}} N_{i,j} + K_{i,j}\right) \quad (12)$$

Suppose there is a market for both GHG emissions and N leaching, then this implies that $P_N > 0$ and $P_G > 0$. Solving for the profit maximizing N leaching, $N_{i,j}^*$, we get:

$$\frac{\partial \Pi_{i,j}}{\partial N_{i,j}} = x_i(2\alpha_j N_{i,j} + \beta_j)P_j - \left(\frac{P_\theta}{\phi_{N1i,j}} + P_N + P_G\left(\frac{\phi_{G1i,j}}{\phi_{N1i,j}}\right)\right) = 0$$

$$N_{i,j}^* = N_{i,j}^*(x_i, P_j, P_\theta, P_N, P_G) = \frac{\left(\frac{P_\theta}{\phi_{N1i,j}} + P_N + P_G\left(\frac{\phi_{G1i,j}}{\phi_{N1i,j}}\right)\right) - \beta_j P_j x_i}{2x_i\alpha_j} \quad (13)$$

Substituting Equation (13) into the profit function (12), we get $\Pi_{i,j}(N_{i,j}^*(x_i, P_j, P_\theta, P_N, P_G),\ x_i, P_j, P_\theta, P_N, P_G)$. The farmer selects the optimal type of farm production activity, j, by solving the argmax problem as shown in Equation (3). After solving the problem in Equation 3, we will have $\Pi_{ij}^{**}$, which is the maximum profit from the three different types of farm production activity, and $N_{i,j^*}^*$ is the corresponding optimal N leaching that maximizes $\Pi_{i,j}^{**}$.

For a given $x_i$, $P_j$, $P_\theta$, and $P_G$, Figure 2 shows how dairy, sheep/beef, and forestry profit changes for an individual farmer i as the permit price of N changes. Figure 3, which is directly below the profit functions, shows the corresponding N leaching for the different farm production activities. While the profit functions are continuous, there may be discontinuity in N leaching when changing from one farm production activity to another. Hence, if there is very little variation in the level of $x_i$ (e.g. land quality) across farms, when a change in $P_N$ passes a certain threshold, we would expect a rather large overall shift from one farm production activity to another. If farmers were heterogeneous (i.e. if there is a high variation in the level of $x_i$ across farms), then we would expect a more gradual change in land-use as $P_N$ changes.

**Figure 2: Relationship between Profit under Different Farm Productivity Activity and Permit Price of N**

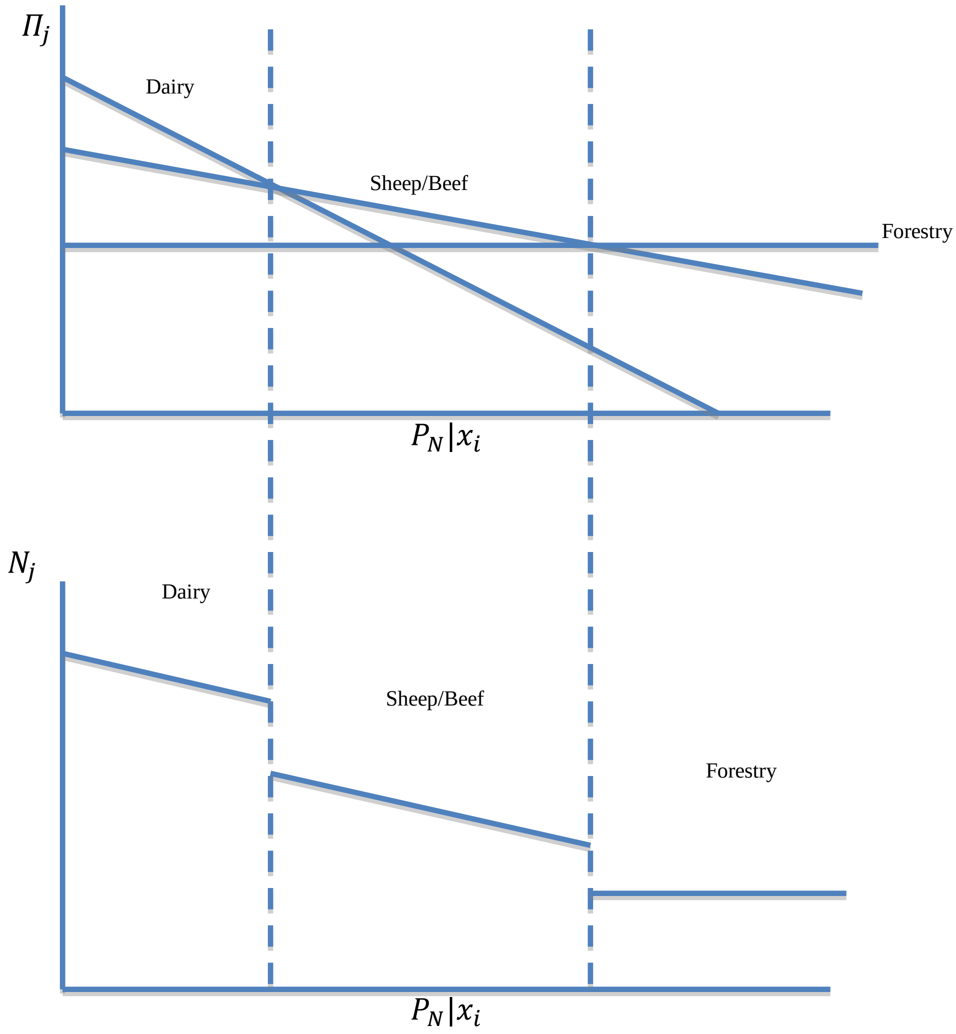



**Figure 3: Relationship between N Leaching and Permit Price of N (above)**

## 3.1. Aggregate Price Relationship with a Quadratic-Linear Functional Form

In this section, we calculate comparative static analysis when the production function has a quadratic form and the relationship between GHG emissions and N leaching is linear. Equation (13) implies the level of nutrient leaching and GHG emissions decreases as their respective permit price increases. Nutrient leaching is decreasing in $P_N$ since

$$\frac{\partial N_{i,j}^{*}}{\partial P_N} = \frac{1}{2x_i\alpha_j} \tag{14}$$

and $\alpha_j < 0$, so $\frac{\partial N_{i,j}^{*}}{\partial P_N} < 0$.

The relationship between GHG emissions and N leaching is found by substituting Equation (13), the optimal N leaching, into Equation (10) to gives Equation (15) below:

$$GHG_{i,j}(N_{i,j})^{*} = \frac{\phi_{G1i,j}}{\phi_{N1i,j}}\left(\frac{\left(\frac{P_\theta}{\phi_{N1i,j}}+P_N+P_G\left(\frac{\phi_{G1i,j}}{\phi_{N1i,j}}\right)\right)-\beta_j P_j x_i}{2x_i\alpha_j}\right)+K_{i,j} \tag{15}$$

The partial derivative $\frac{\partial GHG_{i,j}^{*}}{\partial P_G}$ is negative as

$$\frac{\partial GHG_{i,j}^{*}}{\partial P_G} = \frac{\left(\frac{\phi_{G1i,j}}{\phi_{N1i,j}}\right)^2}{2x_i\alpha_j} \tag{16}$$

and $\alpha_j < 0$, so $\frac{\partial GHG_{i,j}^{*}}{\partial P_G} < 0$. Holding other factors constant, we expect the demand for GHG permits to decrease when the GHG emissions permit price goes up. However, other factors won't be constant as we expect the price of N leaching permits, $P_N$, to change endogenously as $P_G$ changes.

From Equation (7), if $N^{+} = \bar{N}$, then the permit price of N leaching $P_N > 0$. Given that, we can derive the relationship between $P_N$ and $P_G$ by using the Implicit Function Theorem. If $N^{+} \leq \bar{N}$, then $P_N = 0$, which implies that $\frac{\partial P_N}{\partial P_G} = 0$. Given that $P_N > 0$, we expect $P_N$ to decrease as the permit price for GHG $P_G$ increases, i.e. $\frac{\partial P_N}{\partial P_G} < 0$. From Equation (7), let:

$$F(x_i, P_j, P_\theta, P_N, P_G) = \sum_{i=1}^{I} N_{i,j^*}(x_i, P_j, P_\theta, P_N, P_G) - \bar{N} \leq 0 \tag{17}$$

Based on the optimal $N^*_{i,j}$ solution in Equation (13), we can rewrite Equation (17) as:

$$F(x_i, P_j, P_\theta, P_N, P_G) = \sum_{i=1}^{I} \frac{\left(\frac{P_\theta}{\phi_{N1i,j}} + P_N + P_G\left(\frac{\phi_{G1i,j}}{\phi_{N1i,j}}\right)\right) - \beta_j P_j x_i}{2x_i\alpha_j} - \overline{N} = 0 \qquad (18)$$

By the Implicit Function Theorem,

$$\frac{\partial P_N}{\partial P_G} = -\frac{\frac{\partial F}{\partial P_G}}{\frac{\partial F}{\partial P_N}}$$

To get each component of Equation (6), we differentiate the sum of Equation (13) for each farmer evaluated at $j^*(i)$, i.e. whether the $i^{th}$ farmer is D, SB, or f.

$$\frac{\partial F}{\partial P_G} = \sum_{i=1}^{I} \frac{\partial N_{i,j^*}}{\partial P_G} \qquad (19)$$
$$= \sum_{i=1} \left[\frac{\phi_{G_{1i,j}}}{\phi_{N_{1i,j}}} \frac{1}{(2x_i\alpha_j)}\right]$$
$$= \sum_{i\in D} \left[\frac{\phi_{G_{1i,D}}}{\phi_{N_{1i,D}}} \frac{1}{(2x_i\alpha_D)}\right] \frac{1}{x_i} + \sum_{i\in SB} \left[\frac{\phi_{G_{1i,SB}}}{\phi_{N_{1i,SB}}} \frac{1}{(2x_i\alpha_{,B})}\right] \frac{1}{x_i} + \sum_{i\in f} \left[\frac{\phi_{G_{1i,f}}}{\phi_{N_{1i,f}}} \frac{1}{(2x_i\alpha_f)}\right] \frac{1}{x_i}$$

Since $\frac{\phi_{G_j}}{\phi_{N_j}} > 0$, $x_i > 0$, and $\alpha_j < 0$, $\frac{\partial F}{\partial P_G} < 0$.

$$\frac{\partial F}{\partial P_N} = \sum_{i=1}^{I} \frac{\partial N_{i,j^*}}{\partial P_N} \qquad (20)$$
$$= \sum_{i=1} \left[\frac{1}{(2x_i\alpha_j)}\right]$$
$$= \sum_{i\in D} \left[\frac{1}{(2x_i\alpha_D)}\right] \frac{1}{x_i} + \sum_{i\in SB} \left[\frac{1}{(2x_i\alpha_{SB})}\right] \frac{1}{x_i} + \sum_{i\in f} \left[\frac{1}{(2x_i\alpha_f)}\right] \frac{1}{x_i}$$

Given that $x_i > 0$, and $\alpha_j < 0$, it follows that $\frac{\partial F}{\partial P_N} < 0$.

Since $\frac{\partial F}{\partial P_G} < 0$ and $\frac{\partial F}{\partial P_N} < 0$, and $\frac{\partial P_N}{\partial P_G} = -\frac{\frac{\partial F}{\partial P_G}}{\frac{\partial F}{\partial P_N}}$, $\frac{\partial P_N}{\partial P_G} < 0$. The equation $\frac{\partial P_N}{\partial P_G}$ can be used to show how the interaction of the two permit systems affects N leaching and GHG emissions. Holding other factors constant, it is clear that $\frac{\partial GHG_j^*}{\partial P_G} < 0$. However, when the NTS (i.e. $P_N > 0$) and the GHG ETS (i.e. $P_G > 0$) are both in place, the sign of $\frac{dGHG_j^*}{dP_G}$ is ambiguous (shown in Equation (21) below).

From Equation (16), $\frac{\partial GHG_j^*}{\partial P_G} < 0$ since $\alpha_j < 0$. We have shown that $\frac{\partial P_N}{\partial P_G} < 0$, hence $\frac{\partial GHG_j^*}{\partial P_N} \cdot \frac{\partial P_N}{\partial P_G} > 0$. The sign of $\frac{\mathrm{d}GHG_j^*}{\mathrm{d}P_G} < 0$ will depend on whether $\frac{\partial GHG_j^*}{\partial P_G} < 0$ is greater than $\frac{\partial GHG_j^*}{\partial P_N} \cdot \frac{\partial P_N}{\partial P_G} > 0$.

$$\frac{dGHG_j^*}{dP_G} = \frac{\partial GHG_j^*}{\partial P_G} + \frac{\partial GHG_j^*}{\partial P_N} \cdot \frac{\partial P_N}{\partial P_G} \tag{21}$$

Similarly, if there is no NTS in place, then $\frac{\partial P_N}{\partial P_G} = 0$. In this case, we would expect N leaching from different farm production activity j to decrease, i.e. $\frac{\partial N_j^*}{\partial P_G} < 0$. However, when the NTS and the GHG ETS are both in place, then $\frac{\partial P_N}{\partial P_G} < 0$ and the sign of $\frac{\partial N_j^*}{\partial P_G}$ is ambiguous. For example, it is possible that $N_{SB}^{GHG^*} > N_{SB}^{NTS^*} > N_{SB}^{NTS-ETS^*}$ but $N_D^{GHG^*} > N_D^{NTS^*}$, and $N_D^{NTS^*} < N_D^{NTS-ETS^*}$. In other words, we cannot expect all farmers i engaged in the same farm production activity j to behave similarly under the combined NTS-ETS policy scenario. Equation (22) shows that the sign of $\frac{dN_j^*}{dP_G}$ depends on whether $\frac{\partial N_j^*}{\partial P_G} < 0$ is greater than $\frac{\partial N_j^*}{\partial P_N} \cdot \frac{\partial P_N}{\partial P_G} > 0$.

$$\frac{dN_j^*}{dP_G} = \frac{\partial N_j^*}{\partial P_G} + \frac{\partial N_j^*}{\partial P_N} \cdot \frac{\partial P_N}{\partial P_G} \tag{22}$$

While we expect levels of GHG emissions and N leaching to differ across different farm production activity j, the sum of the N leaching from all the farmers to catchment does not change as $P_G$ changes as shown in the Equation (23) below:

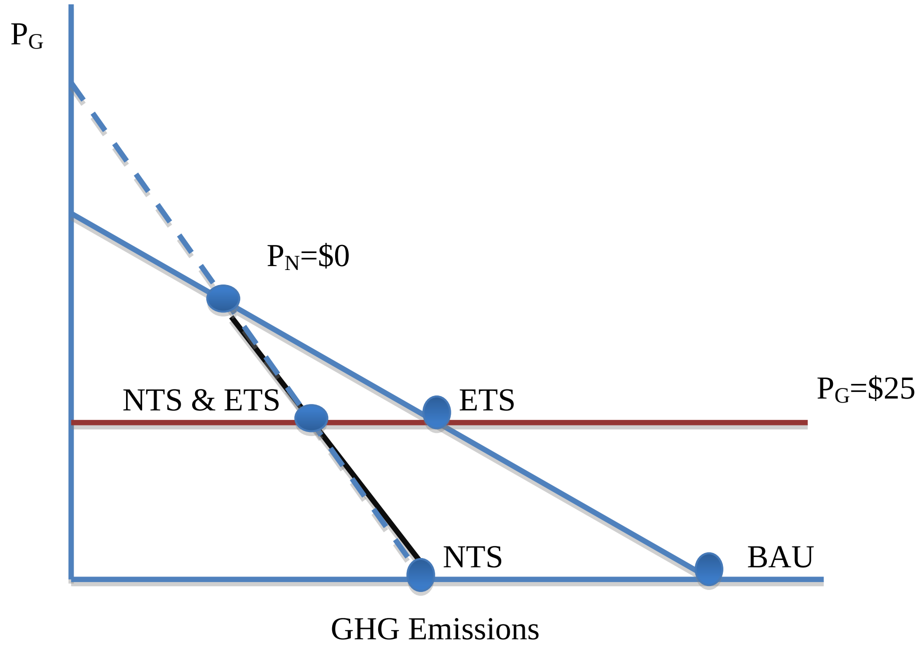
$$\frac{dN^+}{dP_G} = \frac{\partial N^+}{\partial P_G} + \frac{\partial N^+}{\partial P_N} \cdot \frac{\partial P_N}{\partial P_G} \tag{23}$$

$$\frac{dN^+}{dP_G} = \sum_{i=1}^{I} \frac{\partial N_{j^*}^i}{\partial P_G} + \sum_{i=1}^{I} \frac{\partial N_{j^*}^i}{\partial P_N} \cdot \left( - \frac{\sum_{i=1}^{I} \frac{\partial N_{j^*}^i}{\partial P_G}}{\sum_{i=1}^{I} \frac{\partial N_{j^*}^i}{\partial P_N}} \right) = 0$$

When the NTS and the ETS are both in place, an increase in the price of GHG permits will be offset by a decrease in the permit price of N. The permit price of N has to decrease to keep the N leaching pollution constant (i.e. meet the target cap of N set by the government) unless the N cap becomes non-binding. In other words, as $P_G$ increases, it makes using the input $\theta_{i,j}$ (e.g. fertilizer) more expensive as a price on GHG emissions acts like a tax on inputs that increases GHG emissions. Hence, farmers will have an incentive to decrease $\theta_j$. Since $\theta_j$ also affects N leaching, as the level of $\theta_j$ decreases, N leaching decreases implying that the demand for N permits also decreases. As the demand for N permit decreases, the permit price of N decreases as well. While the price of one pollutant increases, the price of another pollutant decreases resulting in no change in the total level of $\theta_{i,j}$ (or total level of N leaching) in the catchment. Hence, while some farmers may decrease N leaching, others will increase N leaching and thus keep the total N loads to the catchment constant.

Figure 4 below illustrates the demand for GHG emissions as a function of GHG price, $P_G$. The point BAU shows the GHG emissions under the situation where neither N or GHG is regulated. When there is a GHG ETS, total GHG emissions decrease up to the point "ETS". When the NTS is in place, it shifts the demand for GHG emissions to the left thus decreasing GHG emissions. The point of intersection of the demand for GHG emissions unde the ETS alone (blue line) and the demand for GHG emissions under NTS (black line) is where $P_N$ =0. At the intersection $P_N$ =0, as the price can't fall below zero, the dotted line does not exist. Figure 4 and Figure 5a illustrate a kinked GHG emissions demand curve. The dotted line does not exist. As the price of GHG increases, it reduces the demand for fertiliser and reduces the need to pay for N permits. For example, as the permit price of GHG increases (and hence the increase in carbon credit), it can lead to an increase in forestry production. Since $\frac{\partial P_N}{\partial P_G}$<0, this reduces demand for fertiliser which in turn drives down the permit price of N leaching. However, as the permit price of N leaching decreases, farmers will have less incentive to increase forestry production. In other words, the inverse relationship between the permit price of N and the permit price of GHG emissions makes the demand for GHG emissions less responsive to a change in the price or GHG. The NTS does not drive down the price of GHG since it is determined in the international carbon market. However, the amount of GHG emissions decreases even more when the NTS is implemented alongside the ETS.

**Figure 4: Demand for GHG Emissions**



The Figure 2a below is the same as Figure 1 above. After the point of $P_N = 0$, the "NTS only" GHG emissions demand curve reverts back to the "ETS only" GHG emissions demand curve. Figure 2b shows the inverse relationship between the permit price of N leaching ($P_N$) and the permit price of GHG emissions ($P_G$). Figure 2c illustrates that as long as $P_N > 0$ the cap on N leaching is binding and the total N leaching does not exceed $\bar{N}$. However, when $P_G$ increases beyond the point where it drives $P_N$ to zero, N leaching decreases.

**Figure 5: Relationship between PG, PN, GHG Emissions and N Leaching**

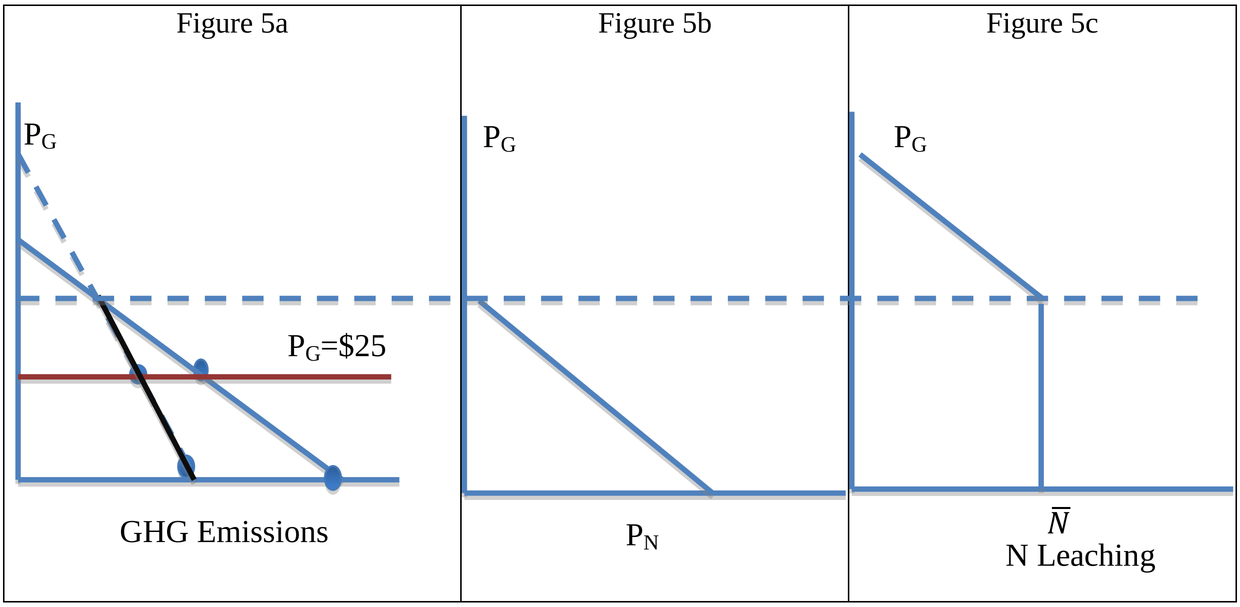
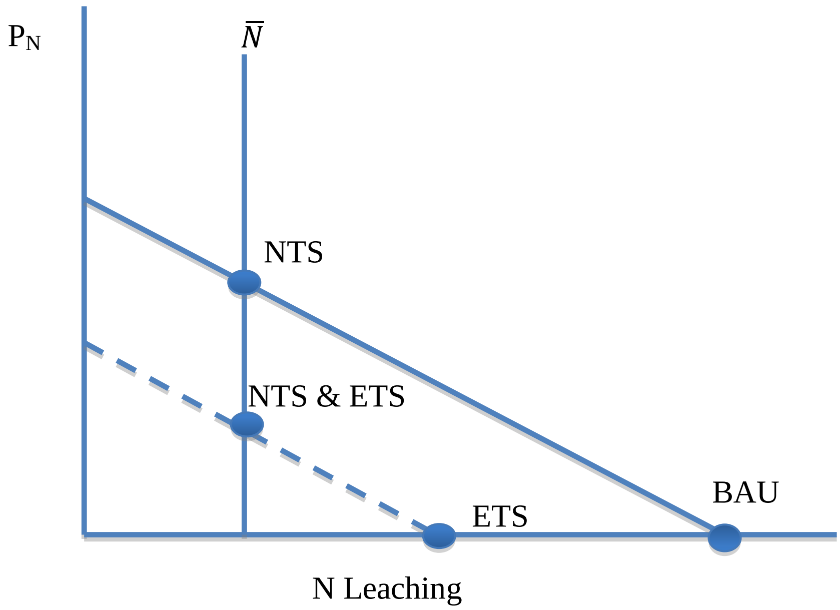


**Figure 6: Demand for N Leaching**




The demand curve for N leaching is illustrated in Figure 6. The point "BAU" shows N leaching under business as usual when the price of $P_N$=0. When there is a cap on N leaching and if the sum of the N entering the catchment is binding, then the permit price of Pn>0. This will decrease the level of N leaching from BAU to $\bar{N}$ as shown in Figure 6. When the GHG ETS is in place it shifts the demand curve for N leaching to the left decreasing the sum of N entering the catchment from BAU. When there is both a NTS and a GHG ETS, total N loading to the catchment stays constant but N permit price falls. The slope of the demand curve for N leaching is the same for when there is a ETS only and when there is a NTS only. This is because the permit price of GHG emissions is determined in the international carbon market, i.e. NZ takes the price of $P_G$ as given. Hence, a change in $P_N$ does not change $P_G$, i.e. $\frac{\partial P_G}{\partial P_N}$=0. In other words, $\frac{dN^+}{dP_N} = \frac{\partial N^+}{\partial P_N} + \frac{\partial N^+}{\partial P_G} \cdot \frac{\partial P_G}{\partial P_N} = \frac{\partial N^+}{\partial P_N}$ since $\frac{\partial P_G}{\partial P_N}$=0.

# PART II

## 4. The NManager Model

This paper extends the NManager model developed by Anastasiadis et al. (2011) to include GHG emissions. NManager is a coupled biophysical and economic model of N leaching from rural land-use in the Lake Rotorua catchment. There are three components to the NManager model: (1) the biophysical model, which simulates the environmental impacts of given nutrient exports on Lake Rotorua; (2) the economic model of landowners' decisions on how they use and manage their land and the resulting ntirogen exports; and (3) NManager models regulations and its impact on farm decisions and environmental outcomes. This section will provide a brief summary of NManager and the ways in which the NManager model in this paper differs from that developed in Anastasiadis et al. (2011). Readers should refer to Anastasiadis et al. (2011) for a detailed exposition of the NManager model.

## 4.1. Modelling the Catchment

The parameters which informs the catchment model in NManager is derived from ROTAN, a catchment level hydrology model developed by NIWA (Rutherford et al., 2008). NManager distinguishes between ‘N exports’, the amount of N discharged as a by product 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 prsence of groundwater lags.

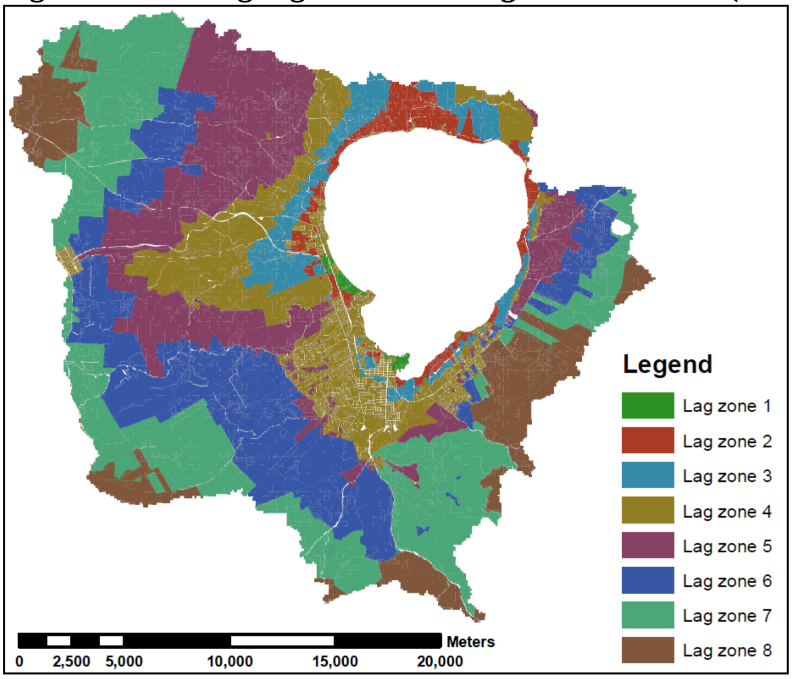
N reaches the Lake via two pathways: (1) via surface water flows, which travels quickly and reaches the lake within a year; and (2) via the groundwater system, which travels slowly and may takes up to 200 years before reaching the lake. Simulations from ROTAN suggest that around 47% of N exports reach 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. Results from ROTAN are used to categorise each parcel of land in the Lake Rotorua catchment into one of 8 lag zone characterised by their mean residence time (MRT), which describes the average amount of time that N is in the groundwater.

**Table 1: Overview of the groundwater lag zones. Source: (Anastasiadis et al., 2011)**

| Lag Zone | 1 | 2 | 3 | 4 | 5 | | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| MRT (years) | 2.5 | 8 | 15 | 30 | 50 | 70 | 90 | 110 |
| Number of ha | 150 | 1,390 | 2,335 | 6,855 | 8,290 | 9,440 | 11,610 | 5,090 |
| Nutrients transported (%) | 0.2 | 3.4 | 5.1 | 12.8 | 19.0 | 25.5 | 24.7 | 9.3 |

**Figure 7: NManager groundwater lag zones. Source: (Anastasiadis et al., 2011)**




Groundwater lags in NManager are described by a series of Unit Response Functions (URFs) constructed from the model of a single aquifer with steady flow. Different URFs are assigned to each lag zone parameterised by their MRT. URFs describe the proportion of N exports, which have entered the groundwater as a function of time since export. Figure 7 gives the cumulative distributions of these URFs. 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. We distinguish between manageable agricultural loads and all other emission loads. This paper only focuses on the manageable loads of N from the agricultural sector.

## 4.2. Modelling Farm Profit, GHG Emissions, and N Leaching

### 4.2.1. Farm Profit Curves

The farmer profit curves are estimated from simulation data of a representative dairy farm and sheep/beef by Smeaton et al. (2011). This dataset include the profit level, GHG emissions, and N leaching that will result under different sets of farm management practices. The carbon credit from forestry production is calculated based on Timar's (Unpublished draft) study, 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 overtime (Timar, unpublished draft). In our analysis, we assume that forest have an unmanageable N load of 4 kg/ha/year (see Anastasiadis et al. 2011). We approximate the relationship between profit and nitrogen leaching as a quadratic function in the level of N leaching by estimating the quadratic coefficients using regression techniques from this simulation dataset. Table 1 (below) gives the coefficient values, and Figure 8, and Figure 9 give the fitted curves of a representative dairy and a sheep/beef profit function under BAU.

**Table 2: Estimated Profit Function Coefficients for Dairy and Sheep/beef Farmers**

| Profit Function | Estimated Profit Function Coefficients | | | |
|---|---|---|---|---|
| | $N^2$ | N | Intercept | $R^2$ |
| Dairy (BAU) | -0.363<br>(0.060) | 46.454<br>(3.182) | -118.675<br>(41.637) | 0.926 |
| Sheep/beef (BAU) | -2.698<br>(0.317) | 88.074<br>(6.899) | -238.11<br>(26.008) | 0.972 |

**Figure 8: Dairy Farm Profit Function**

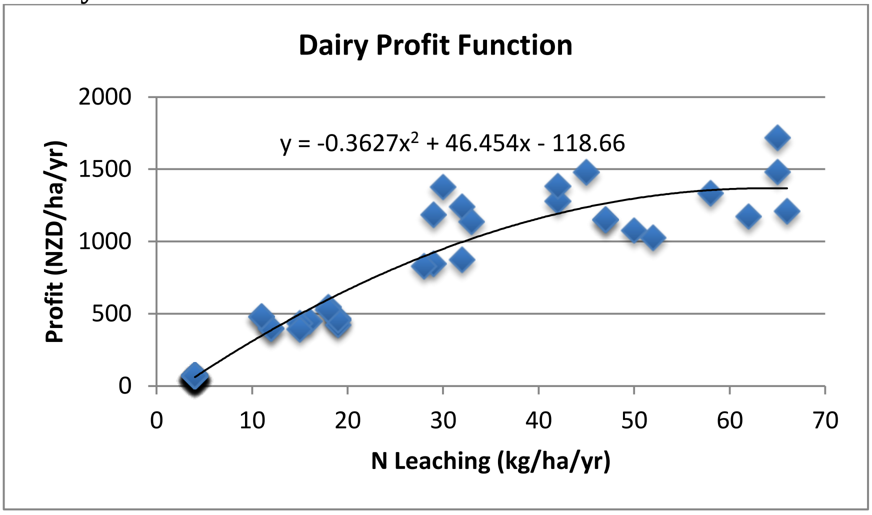
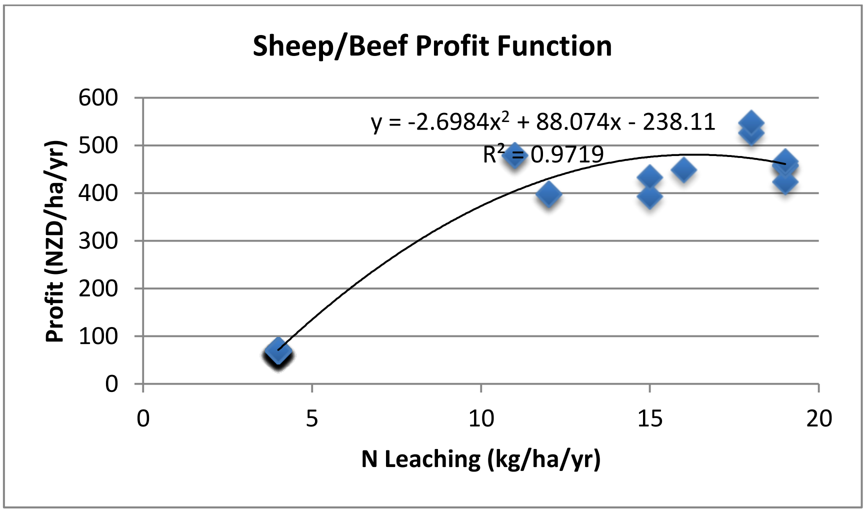



**Figure 9: Sheep/beef Farm Profit Function**




### 4.2.2. GHG Emissions and N Leaching

This paper extends the profit functions used in Anastasiadis et al. (2011) by incorporating the effects of introducing a permit price on GHG emissions. The permit price of GHG emissions is determined exogenously, and is assumed to be $25/tonne of $CO_{2e}$. Similarly, this model assumes that if farmers switch to forestry production, they will receive a carbon credit of $25/tonne of carbon sequestered. The permit price of N, however, is determined enodogenously using the NManager model. The prevailing market price of the N permits is the price that will equalize the total manageable N leaching from the agricultural sector to the cap of 435 tonnes of N/year, a cap set by the Regional Council, to the Lake Rotorua Catchment.

Since a majority of the on-farm air and water pollution mitigation practices considered in Smeaton et al.'s (2011) dataset include changes in farm production intensity (e.g. reducing stocking density), which affects both N leaching and GHG emissions, we treat GHG emissions as a function of N leaching. We assume that there is a linear relationship between GHG emissions and N leaching and there exists certain thresholds of N leaching where the farmer switches from dairy to sheep/beef farm production and to forestry production. These linear relationships between GHG emissions and N leaching for dairy and sheep/beef farms are estimated using ordinary least squares from the simulated data, and reported in Table 3.

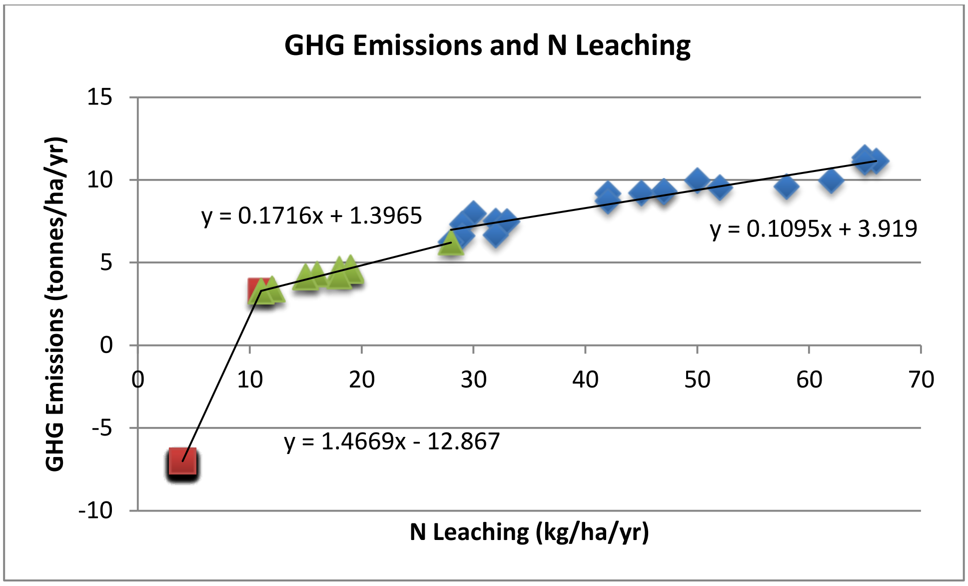
$$GHG_j(N_j) = \begin{cases} r_j N_j + s_j;\ N_j \in (28,65] \\ q_j N_j + w_j;\ N_j \in (11,28] \\ h_j Nj + m_j;\ N_j \in (4,11] \\ -7; N_j = 4 \end{cases}$$

Given that different types of farm production activity has different levels of N leaching, these linear functions can be joined together to form a piece-wise linear function that describe the relationship between GHG emissions and N leaching. Furthermore, this piece-wise linear function specifies 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. If N leaching is between 65 kg/ha/yr and 28 kg/ha/yr, then it means that the farm is under dairy farm production. If it is between 11 and 28 kg/ha/yr, 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 farm production or forestry production. Lastly, if N leaching is 4kg/ha/year, then it means the farm has been switched to forestry production and is sequestering carbon, which is represented by a negative value of GHG emision (-7 tonnes of GHG/ha/year).

**Table 3: Estimated Coefficient Values for GHG Emissions and N Leaching**

| GHG Emissions and N Leaching | Nitrogen (N) | Intercept | $R^2$ |
|---|---|---|---|
| Dairy | 0.1095 | 3.919 | 0.775 |
| Sheep/beef | 0.1716 | 1.3965 | 0.927 |
| Forestry and Sheep/beef (Mix) | 1.4669 | -12.867 | 1 |

**Figure 10: GHG Emissions and N Leaching**




#### 4.2.3. Linking Profits with GHG Emissions and N Leaching

Assuming a piece-wise linear relationship between GHG emissions and N leaching, a farmer i under farm production activity j chooses an optimal level of $N_j$ leaching that maximises his profit. This optimization problem can be expressed as a piecewise function that links N leaching with GHG emissions. Further, the profit function expressed below is analogous to the argmax problem (Equation 3) specified in Section 2. The coefficient estimates $r_j$ and $s_j$ and $q_j$ and $w_j$ below are obtained by regressing GHG emissions and N leaching from dairy and sheep/beef on-farm management practices. The coefficient estimates $h_j$ and $m_j$ 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. If $N_j$ is between [lj, dj] (dj is the N leaching under BAU for dairy farming) and the profit level at $N_j$ is higher than the profit level when Nj=4, then the farmer is abating GHG emissions and N leaching by changing on-farm management practices rather than by switching to forestry production. Given farm profit as a function of N exports and GHG emissions as a function of N, we can also determine the relationship between GHG emissions and profit levels. This enables us to construct an equivalent profit function for farms when there exist only a charge on GHG emissions and non on N leaching.

$$\max_{N_j} \Pi_{i,j} = \begin{cases} a_jN_j^2 + b_jN_j + c_j - P_g\left(r_jN_j + s_j\right) - P_NN_j \text{ if } \mathrm{N_j} \epsilon (\mathrm{l_j}, \mathrm{d_j}] \\ a_jN_j^2 + b_jN_j + c_j - P_g\left(q_jN_j + w_j\right) - P_NN_j \text{ if } \mathrm{N_j} \ \epsilon (\mathrm{m_j}, \mathrm{l_j}\ ] \\ N_j^2 + b_jN_j + c_j - P_g\left(h_jNj + m_j\right) - P_NN_j \text{ if } \mathrm{N_j} \ \epsilon (k_j, \mathrm{m_j}\ ] \\ -7 \text{ if } \mathrm{N_j} = \mathrm{k_j} \end{cases}$$

## 5. Simulating Regulation

### 5.1. GHG ETS

Farmers take the price of GHG permits as given and this model assumes 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. Assuming a piece-wise liner relationship between GHG emissions and nutrient leaching, this model solves for the optimal level of N leaching given a charge of $25/tonne of carbon emitted.

### 5.2. Nutrient Trading Scheme (NTS)

Given the Regional Council cap of 435 tonnes of N/year, the NManager model estimates that the annual level of N allowances for the agricultural sector in the Rotorua catchment to be about 135 ton/ha/year, which is about a 75% reduction of nutrient leaching from the BAU scenario. We match the environment target specified by the Regional Council, with a 100 year phase-in period, during which the cap is progressively tightened.

### 5.3. GHG ETS and NTS Simultaneously

Multiplying the total GHG emissions resulting from different combinations of on-farm management practices under each type of land-use with the GHG permit price of $25/tonne, the cost of GHG emission is then subtracted from the initial level of profit. Since forestry production has a GHG emission of -7 tonnes of GHG/ha/year (i.e. sequestration of 7 tonnes of carbon/ha/year), we assume that profit increases by $25 for each tonne of carbon sequestered. The profit functions are reestimated with the GHG permit price and the new coefficient values are used to estimate the optimal N leaching when there exist both a GHG ETS and a NTS.

## 6. Results

This section shows the results from the numerical simulation when there exists only a GHG ETS or a NTS, and when there exists both a GHG ETS and a NTS. The environmental and economic impact of the three policy scenarios are briefly summarized below. The impact of the different regulations on total N leaching, GHG emissions, the prevailing N permit price, land use change, and the cost of abatement in the Lake Rotorua Catchment are addresed in greater detail below.

*GHG ETS only*

This model shows that under a GHG ETS, dairy and sheep/beef farmer will reduce both their GHG emissions and N leaching from baseline level. Dairy farmers will reduce their N leaching relatively more than sheep/beef farmers. However, both dairy farmers and sheep/beef farmers will reduce their GHG emissions by about the same amount, i.e. 3.35 tonnes/ha/year and 3.18 tonnes/ha/year respectively. While the abatement cost ($/ha/year) is about the same for both dairy and sheep/beef farmers, the total abatement cost, which is calculated as the abatement cost ($/ha/year) multiplied by the acres of land that is sheep/beef farm, is about three times higher than that of of dairy farms. This is because there are three times as many hectares of land under sheep/beef farming than under dairy farming, and there are no changes to land-use under the GHG ETS only policy scenario.

*NTS only*

When only the NTS is implemented, N leaching from dairy farms is reduced by 85% from BAU, which is significantly more than the reduction of N leaching from dairy farms under the GHG ETS only scenario. N leaching from sheep/beef farm is also reduced under the NTS, but only by about 55%, which is not as high compared to the dairy farmers. The economic profit, which is calculated as difference between the new profit under the NTS policy scenario and the cost of the nutrient pollution permits, for dairy farmers is reduced significantly (i.e. from $1,368.80/ha/year to $92.11/ha/year).

*NTS and GHG ETS*

N leaching from dairy farm is higher when there exist both a GHG and N pollution permit markets markets compared to when there is only a market for N. N leaching from sheep/beef farms, however, decrease to zero when both GHG and N are regulated simultaneously. The GHG emission from dairy farming is higher compared to the NTS only policy scenario. Instead of emitting GHG, sheep/beef farmers are sequestering carbon instead. This is because about 100% of sheep/beef farms have been convereted to forestry production. Correspondingly, the abatement cost for dairy farm is lower when N and GHG are regulated simultaneously compared to when there is only a NTS. While the abatement cost for dairy farms decrease, the abatement cost for sheep/beef farms increase by a little more than two times when there exist a market for both GHG and N compared to when there is only a market for N.

#### 6.1.1. Nitrogen leaching

Table 4 and Table 5 summarise the key results for N leaching for dairy and sheep/beef farms under the three policy scenarios. Overall, N leaching decrease by a greater amount under the NTS and the combined GHG ETS and NTS policy scenarios than under the GHG ETS alone. As expected, under the NTS alone and when N and GHG are regulated simultaneously, N leaching decrease by about 74% to reach the 36% of business as usual exports. More interestingly, N exports also decrease by about 23% under the GHG ETS alone. This implies that adopting management practices to optimise profit in the presence of a GHG ETS has a complementary effect on N leaching.

Under a GHG ETS only policy scenario, sheep/beef farmers will reduce N more than dairy farmers. However, under a NTS only dairy farmers will reduce their N leaching significantly more than sheep/beef farmers, i.e. 85% from BAU compared to 54% from BAU respectively (see Table 4 and Table 5). When there exists both a NTS and GHG ETS, dairy farmers reduce N leaching by about 58% from BAU while sheep/beef farmers reduce N leaching by 100% as they switch to forestry production entirely.

**Table 4: Dairy Farm Nitrogen Exports**

| Dairy Nitrogen Leaching | BAU | GHG ETS Only | NTS Only | NTS and GHG ETS |
|---|---|---|---|---|
| N Emissions (kg/ha) | 60 | 49.28 | 9.21 | 25.00 |
| % Reduction from BAU | 0% | 18% | 85% | 58% |
| Total Nitrogen Runoffs (kg) | 321,796.80 | 264,325.27 | 49,406.54 | 134,075.00 |

**Table 5: Sheep/beef Nitrogen Exports**

| Sheep/beef Nitrogen Leaching | BAU | GHG ETS only | NTS only | NTS and GHG ETS |
|---|---|---|---|---|
| N Emissions (kg/ha) | 12 | 8.32 | 5.49 | 0 |
| % Reduction from BAU | 0% | 31% | 54% | 100% |
| Total Nitrogen Runoffs (kg) | 184,502.88 | 127,859.10 | 84,379.32 | - |

#### 6.1.2. Greenhouse gas emissions

The impact of regulation on GHG emissions is shown in Table 6 and Table 7. As expected, total GHG emissions decrease when there exists a GHG ETS. Interestingly, however, the overall reduction in GHG emission is much greater under a policy scenario when GHG and N are both regulated simultaneously than when N and GHG are regulated separately. Since the percentage reduction of GHG emission take into account carbon sequestration, the % reduction exceeds 100%. The simulation model suggests that under a NTS, GHG emissions will be reduced by 125% even when GHG emissions are not charged. GHG emissions will be reduced the most, i.e. by 155% from BAU, when both the GHG ETS and the NTS are in place. The significant reduction in GHG emissions from BAU can be explained by a significant shift in land use from sheep/beef farming into forestry production and the associated carbon sequestration from forest. While the overall GHG emission is reduced the most when N and GHG are both regulated simultaneously, the GHG emission from dairy farming increased slightly compared to the policy scenario when there is a NTS only. This is because some dairy farmers now find it more profitable to stay as dairy farmers compared to sheep/beef farming or forest plantation.

**Table 6: Dairy Farm GHG emissions**

| Dairy GHG Emissions | BAU | GHG ETS Only | NTS | NTS and GHG ETS |
|---|---|---|---|---|
| GHG Emissions (tonnes/ha) | 14.76 | 11.42 | -1.09 | 5.96 |
| % Reduction from BAU | 0% | 23% | 107% | 60% |
| Total GHG Emissions | 79,178.10 | 61,241.24 | -5,834.90 | 31,963.48 |

**Table 7: Sheep/beef Farm GHG emissions**

| Sheep/beef GHG Emissions | BAU | GHG ETS Only | NTS | NTS and GHG ETS |
|---|---|---|---|---|
| GHG Emissions (tonnes/ha) | 3.77 | 0.59 | -1.86 | -7.00 |
| % Reduction from BAU | 0% | 84% | 149% | 286% |
| Total GHG Emissions | 57,955.43 | 8,998.21 | -28,581.37 | -107,626.68 |

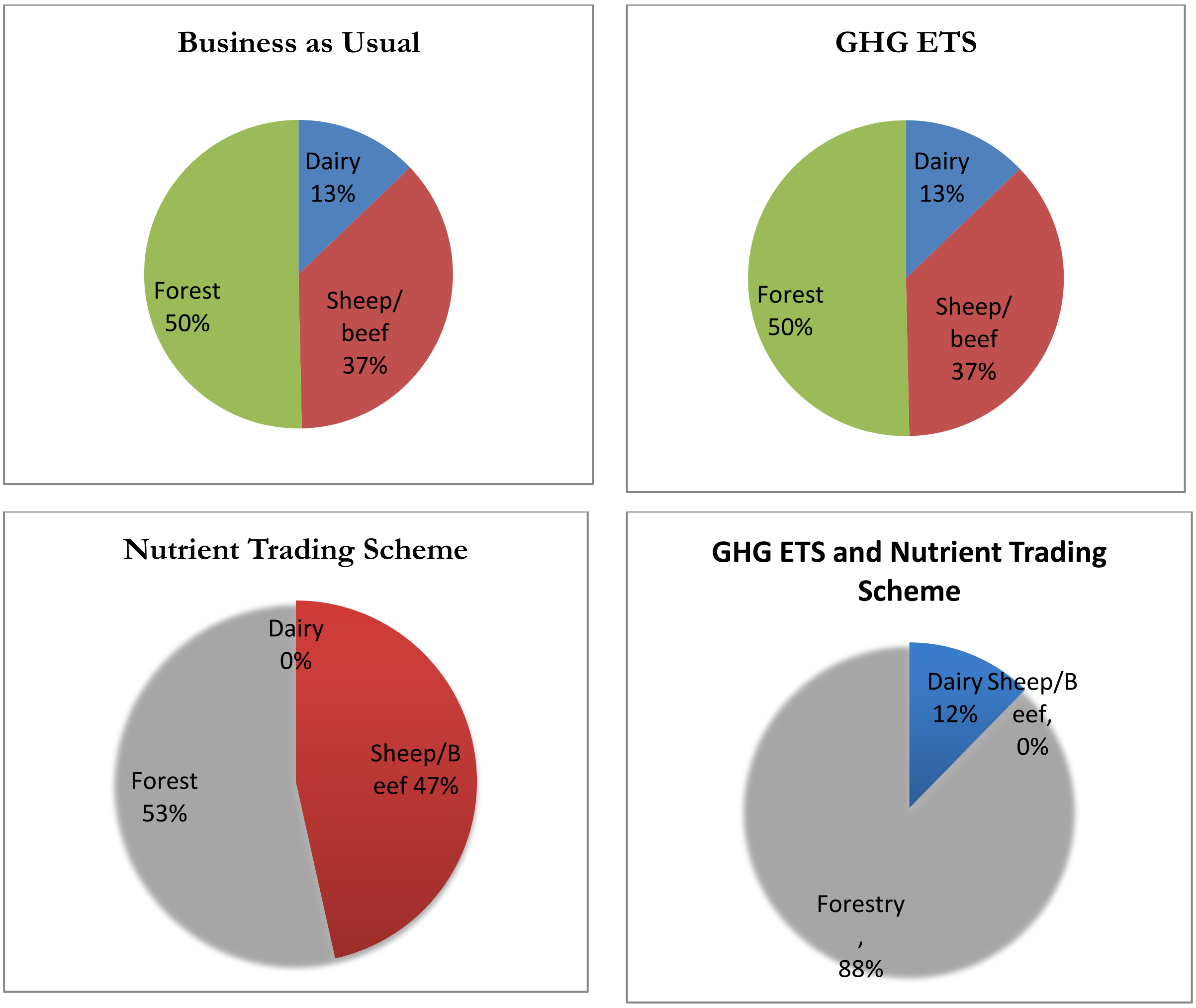
**Table 8: Total GHG emissions and N Discharges in the Lake Rotorua Catchment**

| ROTORUA CATCHMENT AS A WHOLE | BAU | GHG ETS Only | NTS | NTS and GHG ETS |
|---|---|---|---|---|
| Total Nitrogen Runoffs (kg) | 506,299 | 392,184 | 133,785 | 134,075 |
| % of N Reduction from BAU | 0% | 23% | 74% | 74% |
| Total GHG Emissions | 137,133.53 | 70,239.45 | -34,415.96 | -75,663.20 |
| GHG % Reduction from BAU | 0% | 49% | 125% | 155% |
| TOTAL Abatement Cost ($/year) | $- | $885,878.89 | $6,957,732.19 | $8,697,960.73 |

### 6.1.3. Landuse change

Figure 11 shows the land-use change under the different policy scenarios. Implemeneting a GHG ETS only does not result in any land-use change from BAU, indicating that the GHG reductions are met through significant levels of on-farm abatement. However, there is a significant land-use change when the NTS is in place and when there is a market for both GHG and N emissions. Under the NTS alone, 100% of dairy farms were converted to sheep/beef farms and only 9% of the sheep/beef farms were converted to forestry whereas the rest stayed as sheep/beef farm. This occurs because dairy farming is a relatively N intensive land-use. As the price of N is high, sheep/beef farming becomes more profitable than dairy farming. Interestingly, dairy farming increases when GHG regulation is implemented on top of the NTS, while sheep/beef farms decrease to zero when compared to the NTS only policy scenario. This may be explained, as discussed in the section above, partly by the decrease in the N permit price when the two pollutants are regulated simultaneously. Dairy farming is relatively more profitable than sheep/beef farming when GHG and N are regulated simultaneously compared to when N is regulated alone. 100% of sheep/beef farms are converted to forest lands under the combined policy scenario and this is because sheep/beef farm profit fall considerably relative to forestry production.

Figure 11: Land-use Change




#### 6.1.4. Cost of Abatement

The cost of abatement is calculated as the difference between the profit under BAU and the profit under different policy scenarios. While the unit abatement cost ($/ha/year) is about the same for both dairy and sheep/beef farmers when there is only a GHG ETS, the total abatement cost for sheep/beef farmers is about three times higher than that of dairy farmers. This is because there are three times hectares of land under sheep/beef farming than under dairy farming, and there are no changes to land-use under the GHG ETS policy scenario.

The cost of abatement increases about threefold for sheep/beef farmers, but by about 20 times for dairy farmers when the NTS is implemented. The total cost of abatement increase significantly for both sheep/beef and dairy farmers as N leaching from agricultural production has to be reduced by close to 75% to meet the Regional Council target load of 435 tonnes/year to the Lake Rotorua Catchment.

When both NTS and GHG ETS are in place, the abatement cost of dairy farmers decrease quite substantially compared to when there is only a NTS. However, the total abatement cost of sheep/beef farmers increase by about 3 times. This represents a loss in sheep/beef farming profits when sheep/beef farmers shift to forestry production. The abatement cost does not take into account the carbon credits the the sheep/beef farmers would have earned by switching to forestry production.

**Table 9: Cost of Abatement for Dairy Farmers**

| Dairy Farm | N leaching (kg/ha/year) | GHG emissions (tonne/ha/yr) | Farm profit ($/ha/year) | Econ profit ($/ha/year) | Abatement cost ($/ha/year) | Total Abatement Cost ($/year) |
|---|---|---|---|---|---|---|
| BAU | 60.0 | 14.76 | $1,368.80 | $1,368.80 | $- | $- |
| GHG only | 49.28 | 11.42 | $1,326.84 | $1,041.37 | $41.96 | $225,052.77 |
| N only | 9.2 | -1.09 | $431.76 | $92.11 | $937.04 | $5,025,629.69 |
| Both N and GHG | 25 | 5.96 | $920.30 | $245.00 | $448.50 | $2,405,305.50 |

**Table 10: Cost of Abatement for Sheep/beef Farmers**

| Sheep/beef | N leaching (kg/ha/year) | GHG emissions (tonne/ha/yr) | Farm profit ($/ha/year) | Econ profit ($/ha/year) | Abatement cost ($/ha/year) | Total Abatement Cost ($/year) |
|---|---|---|---|---|---|---|
| No regulation | 12 | 3.77 | $480.28 | $480.28 | $- | $- |
| GHG only | 8.32 | 0.59 | $437.30 | $422.67 | $42.98 | $660,826.12 |
| N only | 5.49 | -1.86 | $354.62 | $152.27 | $125.66 | $1,932,102.50 |
| Both N and GHG | 0 | -7 | $71.01 | $246.01 | $409.27 | $6,292,655.23 |

Table 9 and 10 show the loss in economic profits for dairy and sheep/beef farmers. The loss of economic profits is calculated as the difference between the economic profit under BAU and the economic profit under the different policy scenarios. Economic profit takes into account payments for N leaching permits, payments for GHG emissions permits, and carbon credits received. The total loss of economic profit for both dairy and sheep/beef farmers is lower under the combined NTS and GHG ETS policy scenario compared to the scenario when there is only a NTS in place. Finally, the sum of the cost (measured as the loss in economic profits) for regulating each pollution separately is higher than the cost of regulating both N and GHG simultaneously.

**Table 11: Total Loss of Economic Profits (million $)**

| Total Loss of Economic Profits | Dairy | Sheep/Beef | Total Farmers |
|---|---|---|---|
| GHG ETS | $1.8 | $0.9 | $2.6 |
| NTS | $6.8 | $5.0 | $11.9 |
| Both NTS and GHG ETS | $6.0 | $3.6 | $9.6 |

### 6.1.5. Distribution of Costs and Benefits

In this section, we examine the distribution of the costs and benefits of 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) free allocation of the N pollution permits, i.e. farmers receive the optimal level of N permits for free; and (3) grandparenting of N permits with buyback, i.e. farmers are grandfathered the 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 administered, the distribution of the costs and benefits of pollution abatement under each policy scenario can be quite different.

Figure 12 shows the total GHG pollution permit bought and carbon credit received in the Rotorua catchment. How the N pollution permits are administered initially does not change the amount of GHG pollution permit bought and carbon credit received. Under the policy scenario where both the NTS and GHG ETS are implemented, only dairy farmers are buying GHG permits whereas sheep/beef farmers are receiving carbon credits hence there is a significant reduction in the total level of GHG permits sold under the combined NTS and ETS case (see Figure 12).

The net benefits for dairy farmers, sheep/beef farmers, and the Regional Council under different combinations of emissions trading schemes and initial N pollution permit allocation schemes described above are shown in Figure 13, Figure 14, and Figure 15. As shown in Figure 13, regardless of whether the N permits are auctioned or if the Regional Council freely allocates the permits, it costs the dairy farmers less when the GHG ETS is implemented alongside the NTS. This is because when the GHG ETS is implemented alongside the NTS, it decreases the permit price of N. Conversely, if the N permits are grandfathered with buyback from the Regional Council, the dairy farmers will not benefit as much when there exists both a GHG ETS and a NTS. While the permit price of N goes down when there is also a price on GHG emissions, the demand for N permits have also increased compared to the NTS only case. This means that the Regional Council is buying less N permits back from them and hence they will 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 when the N permits are auctioned (Figure 14). 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 benefit slightly less when N permits are auctioned and when there is both a GHG ETS and NTS in place. This is again because the N permit price decreases and sheep/beef farmers have shifted to forestry production and are demanding less N permits. However, if the N permits are grandfathered with buyback, then it would also cost them less since the price of GHG permit decreases the permit price of N.

Figure 12: GHG Permit Bought and Carbon Credit

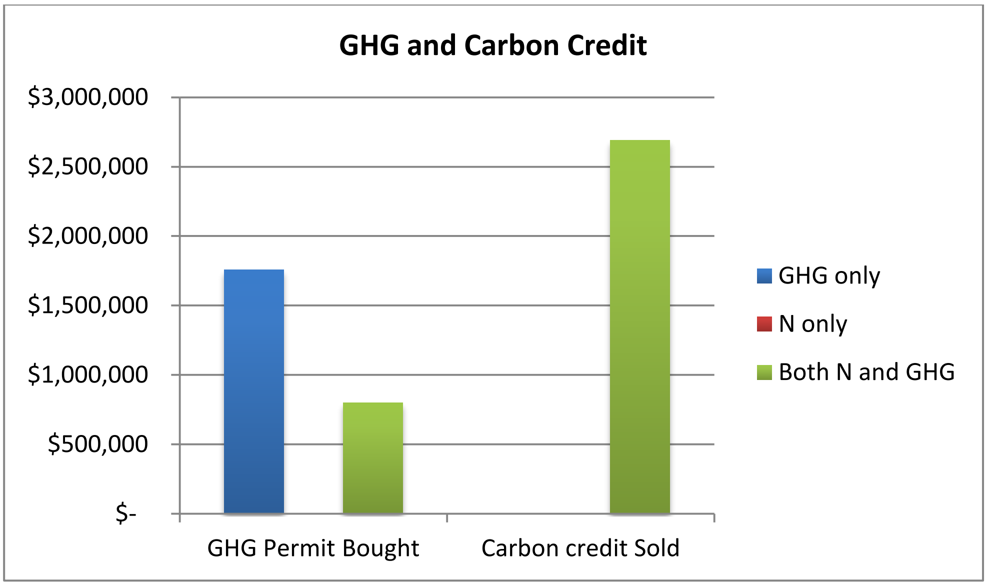



Figure 13: Net Benefits to Dairy Farmers

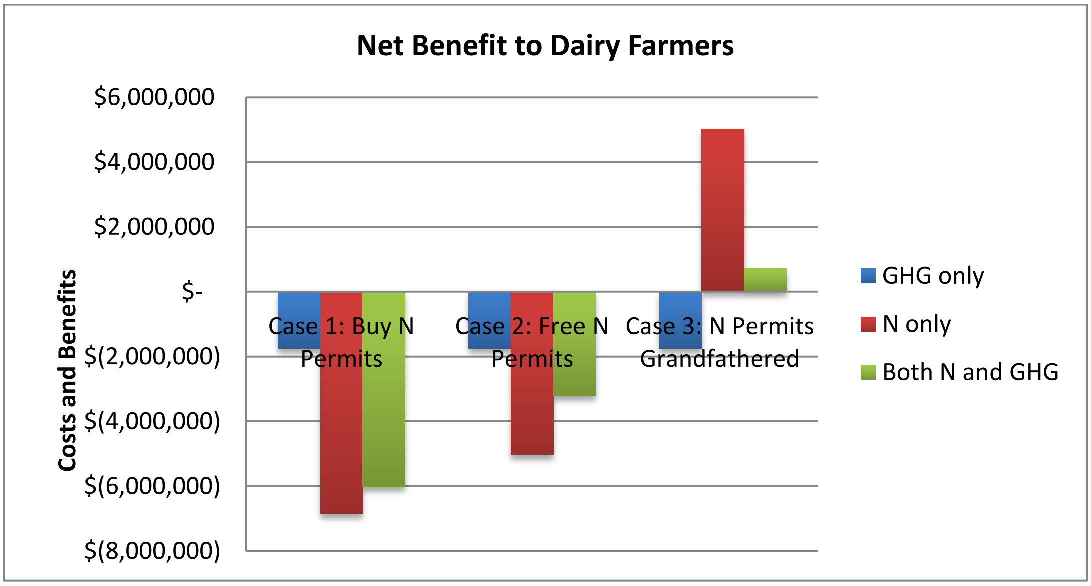


Figure 14: Net Benefit to Sheep/Beef Farmers

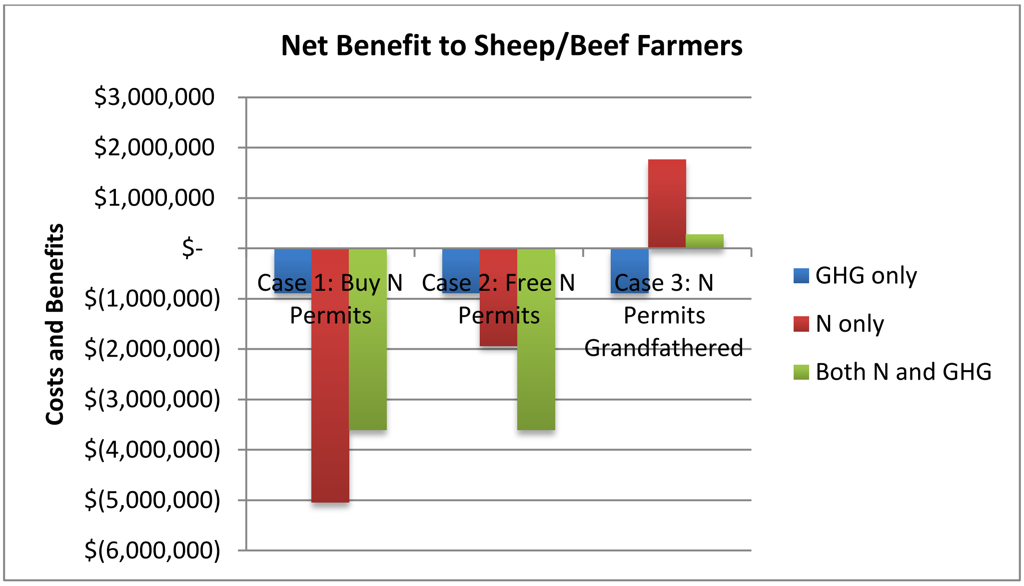
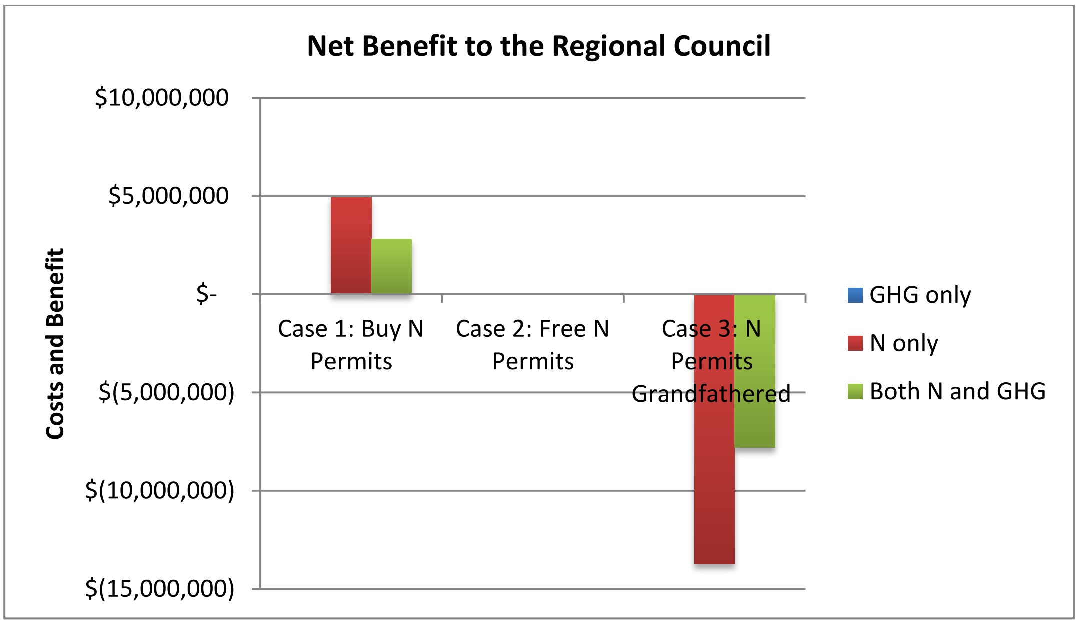



Figure 15: Net Benefit to the




## 7. Conclusion

NTS and GHG ETS may become a reality for farmers in many parts of New Zealand. There is already a NTS in place in the Lake Taupo catchment and nutrient controls are already in place in the Lake Rotorua catchment. From 2015, farmers will face a price for their GHG emissions under the NZ GHG ETS. This paper uses an agro-environmental economic model, NManager, to investigate the interactions of these schemes in the Lake Rotorua Catchment. We examine how the profitability, abatement costs, and 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. We find that total level of GHG emissions decrease when the GHG ETS is implemented alongisde the NTS. Futhermore, the sensitivity of GHG emissions to the permit price of GHG is lower when both tradable pollution permit schemes are in place. The inverse relationship between the permit price of N and the permit price of GHG permits makes the demand for GHG emissions less responsive to a change in the price of GHG permits. However, the converse is not true, i.e. the demand for N leaching does not become less responsive to a change in the price of N permits when both tradable pollution permit schemes are in place. This is because the permit price of GHG emissions does not change as N permit price changes. When there is a cap on total N leaching, the sum of N entering the lake does not change when the GHG ETS is implemented alongside the NTS, but it decreases the permit price of N.

We find that in the Lake Rotorua Catchment there will be interactions between the price of GHG emission permits and the price of N permits. Our results suggest that when both the GHG ETS and the NTS are in place, the permit price of N is lower compared to when only the NTS is implemented. As the permit price of N decreases, it makes it possible for some dairy farmers to continue with dairy farming. Unlike in the NTS only policy scenario, 100% of dairy farmers switch into sheep/beef farming because dairy farming has relatively high N leaching rates and the high permit price of N makes dairy farming no longer profitable. Furthermore, when there is a GHG ETS alongside a NTS, sheep/beef farmers find it more profitable to shift to forestry production instead of staying in sheep/beef farming. The inclusion of agriculture in the GHG ETS creates an opportunity for sheep/beef farmers to change land-use to forestry production and receive carbon credits.

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 administered. In this paper, we considered three different N pollution permit allocation schemes: (1) N permits are auctioned; (2) N permits are freely allocated; and (3) N permits are grandfathered with buyback up to the optimal level of N from the Regional Council. We find that dairy farmers are better off both when the permits are auctioned and when the permits are freely allocated under the combined GHG ETS and NTS policy scenario than in the NTS only policy scenario. Sheep/beef farmers, on the other hand, will experience no change in their net benefits under the combined GHG ETS and NTS policy scenario when either the N permits are auctioned or freely allocated. Our numerical simulations show that when there exists a permit price for GHG emissions and N leaching, 100% of sheep/beef farmers shift to forestry production and hence do not demand any N leaching permits. When the N permits are grandfathered to the respective farmers based on their N leaching level under BAU and then bought back up to the optimal level of N leaching by the Regional Council, dairy farmers benefit greatly under the NTS only policy scenario given their high levels of N leaching under BAU and the high reduction in N leaching

We have assumed that there is 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 effects on 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 these two tradable pollution permit schemes on the prices and levels of emissions of two different but related pollution, we have shown through numerical analysis that the total economic profit loss of having both tradable pollution permit schemes is less than the sum of the economic profit loss of having each pollution permit scheme individually.

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