Specification Of Environmental Emission Trading Options In A Spatial Multi-Agent Simulation Model Of Pastoral Farming

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Summary

A risk efficient frontier for a pastoral farm indicates the optimal enterprise mix that allows the farmer to generate the highest income for a given level of financial risk. It is calculated by matching the available range of enterprises (sheep, beef cattle, deer, dairy, exotic forest and indigenous forest) to the mix of land classes available on the farm. The quantity of environmental emissions produced from the farm varies with the optimal enterprise mix along the risk efficient frontier, and therefore enables the farmer to assess the financial consequences of moving along the frontier to achieve a desired level of environmental emissions. This study uses databases of land cover, land classes and farm boundaries to develop a method for estimating the risk efficient frontier for each farm in the Lake Taupo catchment. The information is used to develop nitrogen trading rules for farmers in a multi-agent simulation framework. The other decision makers in the multi-agent simulation framework are the regulatory institution which sets trading rules and can purchase nitrogen, and the auctioneer who manages the trading protocols. The regulator's cost function for acquiring nitrogen was derived assuming the regulator has full information of the risk efficient frontier of each farmer in the Lake Taupo catchment. Other trading protocols using complete or partial information of the farmers risk efficient frontiers are being developed.

Key Words
Whole farm risk modelling, environmental emissions trading, multi-agent simulation

Introduction

Trading programs that allow pastoral farmers to purchase environmental emission discharge allowances (EDA) from other farmers have the potential to cost-effectively reduce the emission of pollutants from farms into catchments. The success of an emission trading program depends on the institutional framework and the supply and demand for EDA (King and Kuch, 2003). Supply and demand for EDA in turn depend on the ability of the farmer to modify farm plans to manage environmental emissions using available farming enterprises, and the costs and benefits of on-farm environmental mitigation strategies.

Options are being discussed by a regulatory institution, Environment Waikato, to restrict nitrogen discharge from agricultural activity in the Lake Taupo catchment (MAF, 2005; Environment Waikato, 2006). The objective is to improve the water quality in Lake Taupo through the reduction of nitrate leached from pastoral farms in the catchment. The Proposal being considered includes reducing nitrogen flows into the catchment by 20%, capping of nitrogen produced by farms at current levels of nitrogen leached, and allowing the trading of nitrogen discharge allowances between farmers within the catchment.

This study proposes a methodology to characterise the supply and trade in environmental emissions. A risk efficient frontier was developed for each farm in the Lake Taupo catchment and used to provide trading options available to a farmer under an environmental emissions cap. The risk efficient frontier indicates the highest income that can be generated for a given level of financial risk. The farm plan and level of environmental emissions can be calculated for each point on the frontier. The risk efficient frontier will determine a farmer's ability to respond to a demand for EDA based on the farmer's current position on the risk efficient frontier, and the financial implications to the farmer for moving to another position along the frontier.

It is proposed that the generation of supply and demand for EDA by farmers is modelled as an auction process using the multi-agent simulation framework, CORMAS (Common-pool Resources and Multi-Agents Systems) (Bousquet et al.,1998). CORMAS provides facilities to describe spatial entities such as landscape units, and decision making agents such as farmers and the regulatory institution.

The nitrogen discharge allowance trading scheme proposed for the Lake Taupo catchment is used as the basis for the development of the trading model.

The Spatial Multi-Agent Simulation Model

A multi-agent simulation (MAS) can be used to describe the interaction between farmers to supply and purchase emission discharge allowances within a regulatory framework, and the resulting financial, environmental and landscape impacts (Bousquet et al.,1998; Parker et al, 2001; Images Project, 2001). In this study, a prototype MAS trading model is being developed in the CORMAS modelling framework.

Entities included in the model are:

(1) Spatial - Landscape (Taupo catchment).
- Land cover.
- LUC (land use capability class).
- Land parcels (i.e. farm boundaries).

(2) Social - Communicating Agents
- Regulatory Institution – Set cap for individual farmers and reduce total catchment nitrogen discharge allowance.
- Auctioneer - Manage a centralised contract protocol.
- Farmers – Base trade on rules and available options. (This is discussed in detail in the next section).
- Farmer Groups (colleagues, friends, neighbours) - Used to link farmers who want to trade directly.

(3) Passive
- Mail boxes – Used to send and respond to bids.

(4) Environmental Outputs – displayed over time.
- Nitrogen leached.
- Green house gas emission.

Trading Protocols

A number of trading protocols can be modelled using the MAS model to trade in emission discharge allowances (EDA).

Purchase of EDA by the regulatory institution. The regulatory institution, in theory, knows the quantity of emissions each farmer is allowed to discharge into the catchment and should therefore be able to identify potential suppliers of emissions to meet the total catchment discharge allowance at minimum cost to the institution.

Trading of EDA by farmers using a centralised protocol. An auctioneer offers to purchase/sell EDA to all farmers. The best proposal received by the auctioneer from the farmers is then accepted.

Trading of EDA through farmer networks. In this case, farmers in a network (of friends, acquaintances) reach a mutual agreement between themselves to purchase/sell EDA.

Whole Farm Risk Model (WFRM)

It is assumed that a pastoral farmer selects a portfolio of farming enterprises to minimise financial risk at a desired level of income. Environmental emissions, such as nitrate leached and green houses gases emitted, can be calculated from the risk efficient farm plan (Dake et al., 2005). General formulations of risk efficient models, where the main purpose is to determine income and financial risk trade-offs, can also be found in Anderson et al. (1977). Teague et al. (1995) and Ekman (2002) formulated risk efficient models that specifically included environmental emissions and their targets as constraints alongside resource constraints.

The WFRM developed in this study comprises 3 sub-models:

(a) Expected gross margin and variance of gross margin (E-V) sub-model.
(b) Environmental emissions sub-model. Emissions included in this model are nitrate (NO_3) and green house gases (GHG).
(c) Sale and purchase of emission discharge allowance decision-rule sub-model.

<u>E-V sub-model</u>

The model is developed for six farm enterprises (FE) and eight land use capability classes (LUC) based on their suitability for cropping, pastoral and forestry production.

FE = (Sheep, Beef Cattle, Deer, Dairy, Exotic Forestry, Indigenous Forest).
LUC = (Class 1 to Class 8: versatility of use decreases from Class 1 to Class 8).

The main equations of the model are:

Minimise V (1)

subject to:

$$C\,X = F \quad (2)$$
$$AX = Y \quad (3)$$
$$BX \leq Z \quad (4)$$
$$X \geq 0 \quad (5)$$

Where

X = 48 activity levels derived from the matrix of FE and LUC of area (ha) allocated.
V= variance-covariance of farm gross margin of activity X.
A = matrix of ones.
B = pasture dry matter intake per ha (kg DM/ha) if X is a livestock activity.
Y = area of each LUC in the farm.
Z = total pasture (kg DM) available of each LUC.
C = expected gross margin of X ($/kg DM pasture, $ /ha for forest).
F = parametric target farm gross margin from the minimum to the maximum gross margin.

It should be noted that Equation (3) ensures that all land is allocated to the activities thereby ensuring that land is not "abandoned".

Other restrictions imposed on the model are:

Dairy is unsuitable for LUC classes 5 to 8.
Exotic Forestry is unsuitable for LUC class 8.
A sheep to cattle carried ratio may be specified.

The environmental sub-model

Two environmental emissions, nitrate loss (kg N/ha/yr) and GHG (kg CO_2 equivalents /ha/yr), are modelled for sheep, beef cattle, deer and dairy. Mean annual carbon increment (which measures the rate at which forests gain net CO_2) is used for Exotic Forestry and Indigenous Forest activities.

Emission rates for livestock are estimated approximately from the OVERSEER® nutrient balance model (Wheeler et al. 2003) and fitted to a polynomial equation.

$$Y_i = a_i Z^2 + b_i Z \quad (6)$$

$$U_i = u_i \quad (7)$$

Where
i = nitrate or GHG.
Y_i= nitrate (kg N/ha/yr) or GHG (kg CO_2 equivalents /ha/yr).
Z = stocking rate (su/ha).
a_i, b_i = parameters.
U_i= coefficient of variation of Y.
u_i = parameter.

It is assumed that the emissions (Y) have a lognormal distribution with a coefficient of variation U.

In the case of Exotic Forestry and Indigenous Forest activities the mean annual carbon increments have been obtained from the database maintained by Motu Economic and Public Policy Research (2005).

Trade in emission discharge allowances (EDA) decision-rule sub-model.

The variable outcomes from a risk efficient portfolio of enterprises can be replaced by a risk-adjusted expected return which measures the farmer's indifference between risk-free cash payments and the variable outcomes. A farmer who wishes to sell EDA would need to replace their current risky portfolio with an alternative risky portfolio of farming enterprises that has a lower EDA plus risk free cash payments for the EDA that have been released. The cost to the farmer for reducing an EDA can therefore be measured as the difference between the risk-adjusted expected returns of the current and the alternative portfolios.

The risk-adjusted return of the portfolio is estimated from an assumed utility function of the farmer for variable returns. If the farmer's utility function for wealth can be approximated by a negative exponential function, then for normally distributed farm returns the expected utility can be stated as a linear function of expected return and variance (Sharpe, 1999; Hardaker, 2000)

$$eu = e - v/t \quad (8)$$

and re-arranged as

$$t = v/(e - eu) \quad (9)$$

Where eu is the expected utility, e is the expected outcome, v is the variance of the outcome and t is the risk tolerance.

The term v/t is the risk penalty, and the term eu is also known as the risk-adjusted return or certainty equivalent.

The quantity of EDA, for example nitrogen discharge allowance, available for trading, can be determined by solving the E-V and the Environment sub-models for two levels of target farm gross margin. One solution is the farmer's current position on the risk efficient frontier (where the farmer has been capped), and second solution is an alternative position on the risk efficient frontier that the farmer may wish move to while trading in EDA.

Using the following definitions

G_1, G_2 =	Expected gross margin at the farmer's current position on the risk frontier (G_1) and an alternative position (G_2).
S_1, S_2 =	Risk (standard deviation of gross margin) at the farmer's current position on the risk frontier (S_1) and an alternative position (S_2).
R_1, R_2 =	Risk-adjusted expected gross margin at the farmer's current position on the risk frontier (R_1) and an alternative position (R_2).
EDA_1, EDA_2 =	EDA at the farmer's current position on the risk frontier (EDA_1) and an alternative position (EDA_2).
EDA_S =	Emission available for sale.
C =	Cost to the farmer of EDA sale.
GM_f =	Risk-free return formed by a line tangent to the farmer's current position on the risk frontier (See Figure 1).

Assuming the farmer's current position on the efficient frontier reflects the farmer's preference for risk, then Equation (9) can be used to approximate the risk tolerance (t) as

$$t = \quad S_1^{\wedge 2} / (G_1 - GM_f) \qquad (10)$$

which can then be used to calculate R_2 using Equation (8)

$$R_2 = \quad G_2 - S_2^{\wedge 2} / t \qquad (11)$$

Two cost options for EDA sale are:

(a) If $EDA_1 > EDA_2$ and $R_1 > R_2$ Then $EDA_S = EDA_1 - EDA_2$ and $C = R_1 - R_2$

(b) If $EDA_1 > EDA_2$ and $R_1 < R_2$ Then $EDA_S = EDA_1 - EDA_2$ and $C = 0$ (or C = small token value)

The second case implies that the farmer can reduce EDA and still increase the risk-adjusted return.

Model Implementation

The MAS emissions trading model was applied to the Taupo catchment to determine the cost to an institution (Environment Waikato or a Trust) wishing to purchase nitrogen discharge allowances from farmers in the catchment. Verification of the MAS model to simulate purchase of nitrogen discharge allowances by farmers using a centralised auctioning protocol and through farmer networks is in progress.

Data

Three sources of spatial data were used in the modelling:

- Landcover Database for vegetation cover (LCDB2).
- New Zealand Land Resource Inventory for land use and versatility (NZLRI).
- Agribase for farm boundaries and enterprises.

The three data sources were combined and simplified (re-categorised) in a GIS environment to produce a standardised data source for the WFRM model described by Equations (1) to (5). Gross margin templates were developed using historical data and complemented with farm budgets produced by the NZ Ministry of Agriculture and Forestry farm monitoring reports to calculate expected gross margin and variance of gross margins for data required by Equations (1) and (2) and feed intake data required by Equation (4). Forestry gross margins were adapted using data from Knowles et al. (2003). Gross margins for indigenous forest were assumed to be zero. The total pasture available was estimated from the average potential carrying capacity reported in the New Zealand Land Resource Inventory database.

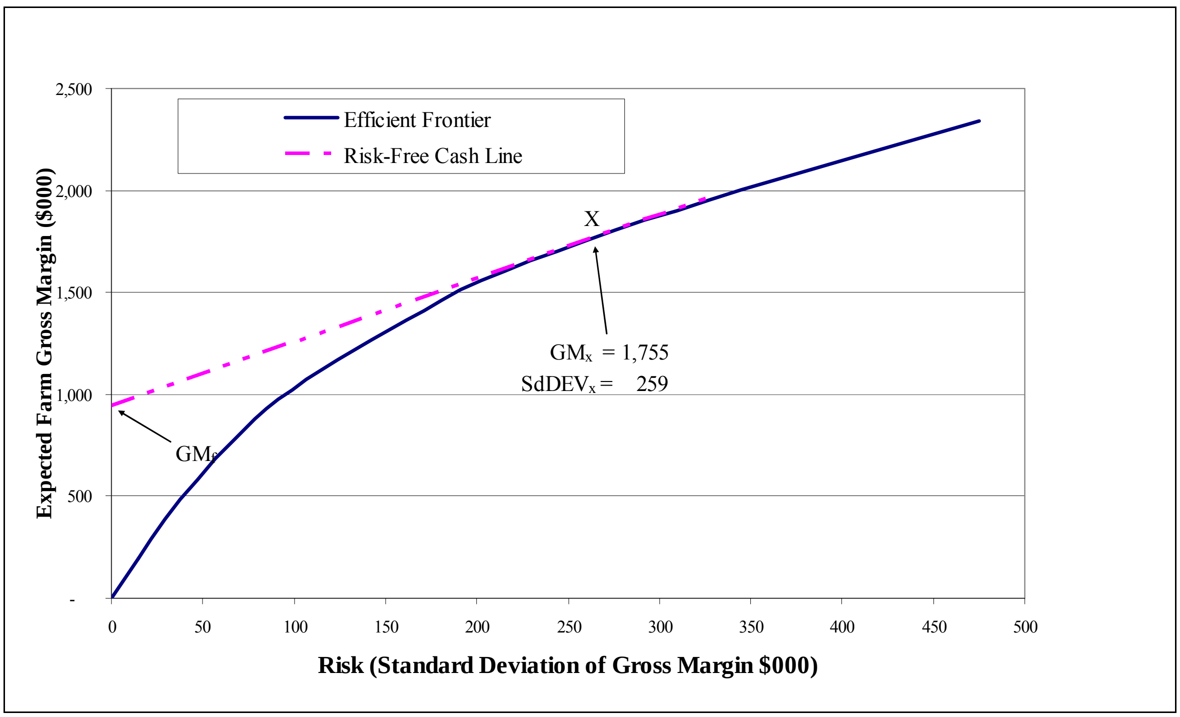
One hundred farms larger than 50 hectares and designated as livestock, forestry and indigenous forest and native bush types in the Agribase database were included in the MAS trading model.

Results

Farmer Selling Rules And Options

The WFRM has a quadratic objective function with linear constraints. It is solved using the solver from Frontline Systems (2003) in Microsoft Excel for each of the 100 farms in the catchment. Figures 1 shows the risk efficient frontier of one of the farms. It indicates maximum farm gross margin achievable for a given level of risk.

Figure 1: Risk Efficient Frontier for a 1,300 ha Farm



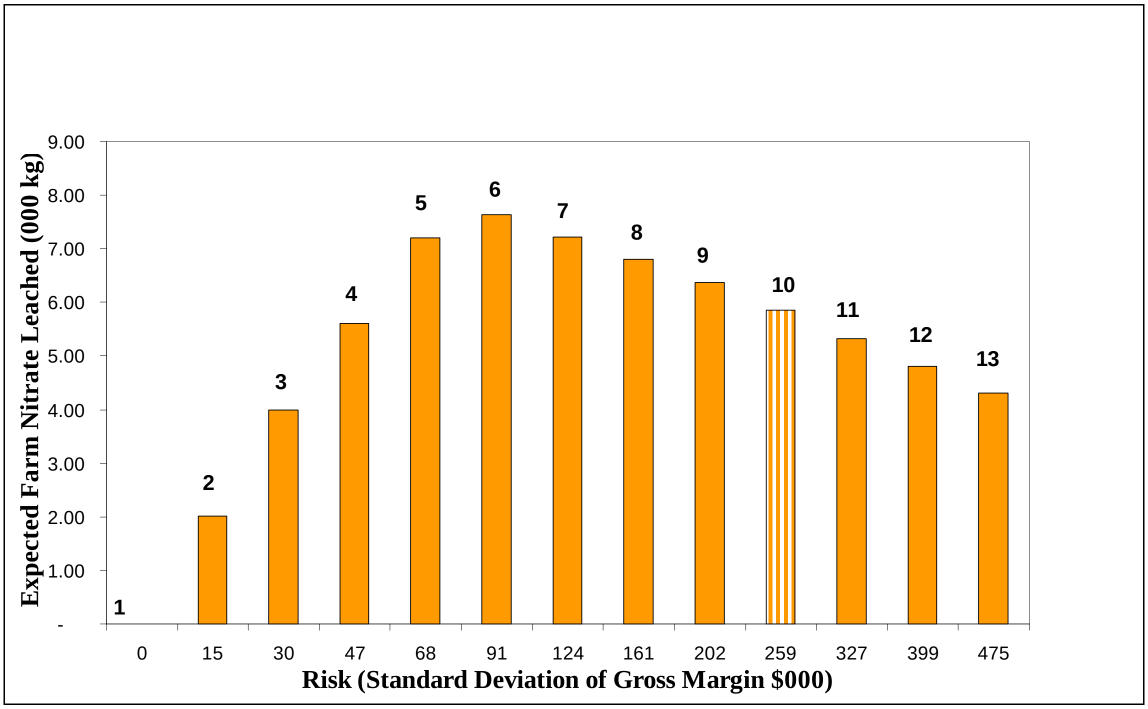
Assuming X is the farmer's current position on the efficient frontier, then the expected gross margin and standard deviation are $ 1,755,000 and $259,000 respectively. The Risk-Free cash line which is tangent to the frontier at point X indicates that the farmer would be indifferent between the variable returns at point X with receiving $ 942,000 without risk (GM_f in Figure 1).

Figure 2 shows the optimal portfolio of enterprises (optimal farm plans) that correspond to points on the efficient frontier shown in Figure 1. The optimal farm plan yielding little or no income (and therefore little or no risk) is to have most of the farm in indigenous forest. When high income (more risk) is desired then the optimal farm is to have most of the area in dairying and exotic forestry.

Figure 2: Farm Plans Corresponding to Efficient Frontier for a 1,300 Ha Farm

Assuming that the farm is capped at the point indicated by column 10 (vertical strip pattern) in Figure 3, then the allowable nitrogen that can be leached by this farm is about 5.85 t N /yr. It can be seen that the farmer would have nitrogen available for sale if the farmer is prepared to move to other farm plans (Figures 2 and 3, Columns 1, 2, 3, 4, 11, 12 and 13).

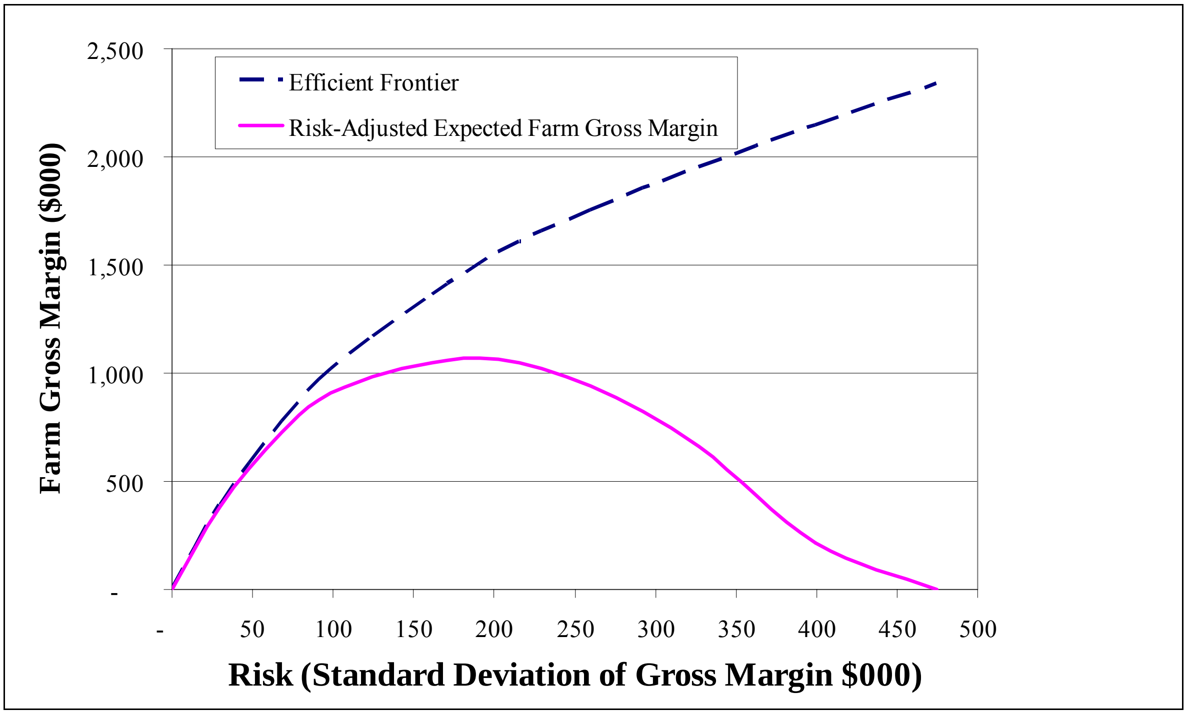
Figure 3: Risk Efficient Frontier and Nitrate Leached for a 1,300 ha Farm capped at Column 10



The farmer would need to purchase nitrogen discharge rights to move to farm plans represented by Columns 5, 6, 7, 8, and 9 in Figures 2 and 3.

Using Equations 10 and 11 the risk-adjusted farm gross margin can be estimated for points along the efficient frontier (Figure 4) and used to calculate the cost to the farmer for providing EDA for sale. It can be noted that the farmer's utility function may result in a high risk penalty for high gross margin outcomes thereby resulting in low risk-adjusted expected farm gross margins.

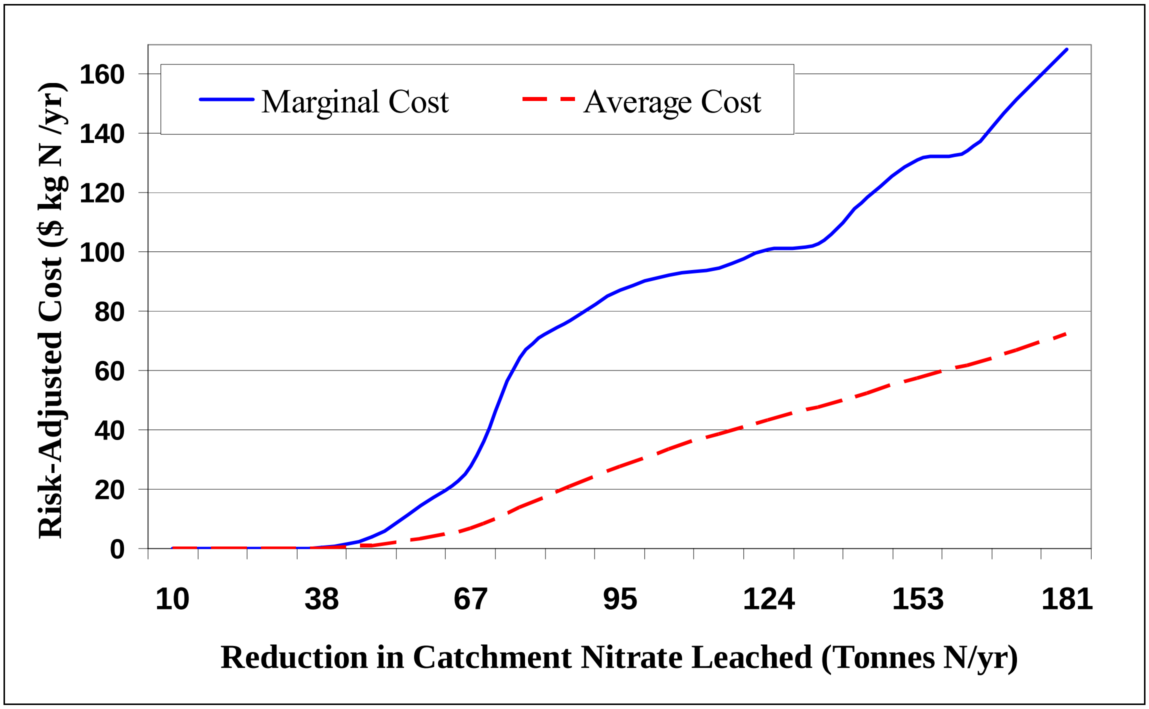
Figure 4: Efficient Frontier and Corresponding Risk-Adjusted Expected Farm Gross Margin for a 1,300 ha Farm



Aggregate Supply Function Of Nitrogen Discharge Allowances

The regulatory institution may wish to purchase nitrogen discharge allowances from farmers in order to reduce the overall nitrate leached into the catchment. The regulatory institution knows each farmer's risk efficient frontier and the position on the frontier where each farmer has been capped, as this can be derived from the farm plan when "consent" for nitrogen discharge allowances is being set for the farmer. Using the approach outlined in the previous section, the nitrogen discharge allowances available to be sold can be determined and the risk-adjusted cost to the farmer in lost income can be calculated. Assume all the farmers are capped at random points on their risk efficient frontiers (representing their current positions on the efficient frontier), and the regulatory institution decides to compensate the farmer for income loss to give up their nitrogen discharge allowances, then potential suppliers can be identified using an optimisation process that minimises cost to the regulatory institution to meet demand. Figure 5 shows the marginal and average cost to the regulatory institution to acquiring nitrogen discharge allowances to the maximum of about 190 t N/yr used in this hypothetical example.

Figure 5: Nitrogen Discharge Allowance Supply Function Assuming 100 Farmers are Capped at Random Levels in the Catchment



Conclusion

The objective of this study was to demonstrate how a whole farm risk optimisation model can be used to specify environmental emission trading rules and options for farmers in a catchment. It is based on specifying a risk efficient frontier for each farmer which indicates trade-offs between income and financial risk at the whole farm level, the associated optimal farming enterprise mix (farm plans) and emissions from the farm. The whole farm risk model can be used to calculate the quantity of emission discharge allowance that the farmer can supply for sale below a cap or purchase from other farmers to exceed the cap.

A multi-agent modelling framework has been proposed to link the trading decision making agents (regulatory institution, farmers and auctioneer) to the landscape, vegetation cover, land class, and potential faming enterprises. The multi-agent model was applied to the Taupo Catctment to illustrate how the model could be used to manage trade in nitrogen discharge allowances in the catchment. Marginal and average cost to the regulatory institution of acquiring different quantities of nitrogen discharge allowances have been illustrated.

Further development of the multi-agent system is progressing to evaluate a number of nitrogen discharges trading protocols (auctioneer and farmer networks, and supply and price information sharing), and trade in other environmental emissions such as green house gases.

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