Optimal Trade-Offs Between Financial and Environmental Risks in Pastoral Farming

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EXTENDED ABSTRACT

Environmental management systems (EMS) are increasingly being used in New Zealand (NZ) as a management tool to ensure farms are managed in an environmentally sustainable manner. *NZ Farmsure* is an EMS available to sheep, beef, deer, and goat farmers to address production issues in a sustainable manner and create market access opportunities for products. *NZ Farmsure* is based around three plans - an Animal Management Plan, a Land and Environmental Plan, and a Social Responsibility Plan. Specifications for environmentally sustainable farming are contained in the Land and Environmental Plan, and include management options relating to the soil resource, nutrients, water quality, biosecurity, greenhouse gases, vista, and the management of flora and fauna to enhance production, stability and biodiversity.

While it is expected that farmers who use EMS are better placed to minimise environmental damage and meet environmental targets, current EMS do not provide either a convenient or robust way for farmers to evaluate the impact of the potentially large combination of enterprises that can be used to achieve desired environmental targets. These impacts must be assessed through their combined effects on farm profitability, farm financial risk, and the ability of the farm to reliably meet the environmental targets.

This study describes a farm scale risk optimisation model (FSRM) that can be used to evaluate farming options that a farmer can use to trade-off financial and environmental risks at the whole farm level. Enterprise options available to pastoral farmers include livestock production, cropping, plantation forestry, native bush, and riparian management activities. Incomes from these enterprises are risky because they vary from year to year due to variable yields and prices. Farm emissions, such as soil losses, nitrates and green house gasses, also vary from year to year due to biological processes and climatic factors.

When a given collection of enterprises is matched with land suitability, the selected portfolio of enterprises determines the level of income and financial risk that the farmer is prepared to accept. It also determines the level and variability of emissions. In order to minimise environmental impacts associated with farm emissions, targets and guidelines may be set by regulatory authorities. A farmer exceeding environmental targets would need to modify his or her farming operation to comply. This invariably would involve either a reduction in farm income, an increase in the income risk, or the risk of not meeting environmental compliance standards.

FSRM can be used to calculate a *risk efficient frontier*. This indicates the highest income that can be generated for a given level of financial risk. The farm plan and level of environmental emissions are also provided. The risk efficient frontier can be used to determine a farmer's ability to respond to regulation on emissions based on the farmer's current position on the risk efficient frontier, and the extent to which he or she is prepared to move along the frontier curve while trading off financial outcomes in order to satisfy regulations on environmental emissions.

FSRM was developed using a 1207 hectare case study farm of sheep, beef cattle, deer, native bush, plantation forestry and riparian enterprises. These were allocated to land classes, to maximise mean farm gross margin at a given level of gross margin risk. Gross margins templates with stochastic prices and yields were developed for each farming enterprise, and the mean and variance of gross margin generated using the @Risk Monte Carlo simulation package. The risk programming model is developed in the Microsoft Excel spreadsheet and solved using the Frontline Solver. Variance of farm gross margin is used as the measure of gross margin risk, and it is minimised for expected farm gross margin.

1. INTRODUCTION

A framework to evaluate farming opportunities that a farmer can use to trade-off financial and environmental risk at the whole farm level would greatly assist pastoral farmers to better manage their business operation at a time when production goals must include a greater evaluation of environmental impacts. Trading off production with environment objectives adds to the complexity of farm planning and decision making in mixed livestock farming systems. A trade-off framework would add value to Environmental Management Systems (EMS) such as *New Zealand Farmsure*, which provides specifications for Triple Bottle Line reporting (economic, environmental and social) of sheep, beef, deer and goat production systems (Mackay et al., 2002, Parminter et al., 2004). Presently, few EMS offer a systematic or robust way for farmers to evaluate the impact of the potentially large combination of enterprises that can be used to achieve desired environmental targets. Impacts must be assessed through their combined effects on farm profitability, farm financial risk, and the ability of the farm to reliably meet the environmental targets.

The *NZ Farmsure* EMS provides specifications for

- The sustainable management of animal health, welfare and production, through an Animal Management Plan;
- Matching farm enterprises to landscape diversity, as a means of enhancing water quality, soil resource, nutrients, biodiversity, and biosecurity, through a Land and Environmental Plan;
- Making socially responsible commitments to employees, local community, and heritage values through a Social Responsibility Plan.

Options available to the farmer to manage risks are contained in the Animal Management and the Land Management Plan. These include various pastoral farming activities, cropping, plantation forestry, native bush and riparian management activities. Enterprise options must then be matched with the land capability classes. Incomes and income-variability are specific to the selected farm plan, and indicates the level of financial risk that the farmer faces with the enterprise mix.

Enterprises that comprise the farm plan may also have uncertain environmental outcomes because emissions from the farm, such as nitrates and green house gasses, vary from year to year due to biological processes and climatic factors. Therefore, targets that are set to minimise environmental risks are likely to be breached and would need to be set carefully to ensure an acceptable probability of non-compliance.

In this study a farm scale risk modelling framework is developed to allow farmers to select the optimal farming system design for the level of risk they are prepared to accept. It also provides a means for farmers to create and evaluate different whole farm scenarios, so they may better select the most promising scenario for trading-off economic and environmental objectives at a given level of risk.

2. THE FARM SCALE RISK MODEL (FSRM)

It is assumed that a farmer has an aversion to financial risk, and is therefore prepared to trade-off mean income with income risk. A farmer would therefore select a portfolio of farming enterprises that would allow the achievement of the highest income for the acceptable level of risk. The formulation of FRSM is designed to determine the optimum enterprise mix and to characterise the farm risk efficient frontier.

General formulation of risk efficient models for the selection of a portfolio of enterprises with resource constraints can be found in Anderson et al. (1977) and McCarl and Spreen (1997). The models may be formulated with the objective of maximising expected net income less the cost of risk (measured as a “risk aversion coefficient” multiplied by the variance of income) or with the objective of minimising risk (the variance of income) for a given level of income. The under achievement of income from a target income can also be used as the measure of risk (Dake and Squire, 1994).

Teague et al. (1995) and Ekman (n.a) formulated risk efficient models that specifically include environmental emissions and their targets as constraints alongside resource constraints. They address issues of the probability of exceeding emission standards and the cost of mitigation strategies aimed at achieving a high reliability of compliance.

The FSRM developed in this study is formulated to determine the portfolio of enterprises in an optimal farm plan, and where the objective is to minimise financial risk (the variance of gross margin) for specified levels of farm gross margin. The constraints in the model are the area of available land classes and pasture produced. Environmental emissions are then calculated for the optimal farm plans.

The model components are: the expected gross margin and variance of gross margin (E-V) sub-model; and the environmental emissions sub-model. Emissions included in this model are nitrate (NO_3) and green house gases (GHG).

E-V sub-model

The model is developed for eight farm enterprises (FE) and six land capability classes (or land management units - LMU) namely:

FE = (Lambs Store, Lambs Finish, Cattle Store, Cattle Finish, Fallow Deer, Pine, Native Bush, Riparian).

LMU = (Flat Land, Moderate Hill, Steep Hill1, Steep Hill2, Retired Land, Riparian).

The main equations of the model are:

$$\text{Minimise } V \quad (1)$$

subject to:

$$C X = F \quad (2)$$

$$AX \leq B \quad (3)$$

$$X \geq 0 \quad (4)$$

Where

V= Variance of farm gross margin (calculated from the variance of the gross margin of X).

X = 48 activity levels derived from the matrix of FE and LMU ; if X is a livestock activity then unit is stock units (su) which is equivalent to an annual pasture intake of 550 kg DM; if X is Pine, Native Bush or Riparian then the unit is hectare (ha).

C = expected gross margin of X.

F = parametric target farm gross margin from the lowest to the maximum gross margin.

A = pasture (kg DM) required annually for X. If X is a livestock activity then A is the pasture intake adjusted for pasture utilisation which vary by LMU; if X is Pine, Native Bush or Riparian then A pasture displaced by X.

B = annual pasture (kg DM) available/grown in each LMU.

Other restrictions imposed on the model are:

Riparian enterprise can be used only on Riparian LMU.

The area in Riparian enterprise must equal the area of Riparian LMU.

Pine is excluded from Flat Land and Moderate Hill LMUs.

A sheep to cattle 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, cattle and deer. Mean annual carbon increment which measures the rate at which forests gain net CO_2 are used for Pine, Native Bush and Riparian activities.

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

$$Y_i = a_i Z^2 + b_i Z \quad (5)$$

$$U_i = u_i \quad (6)$$

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.

In the case of Pine, Native Bush and Riparian activities the mean annual carbon increments have been obtained from the literature (Hall and Hollinger, 1997).

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

3. DATA

The risk model was applied to a 1207 hectare case study farm operating sheep, beef cattle, deer, native bush, plantation forestry and riparian enterprises located in the Central North Island of New Zealand. The farm carries approximately

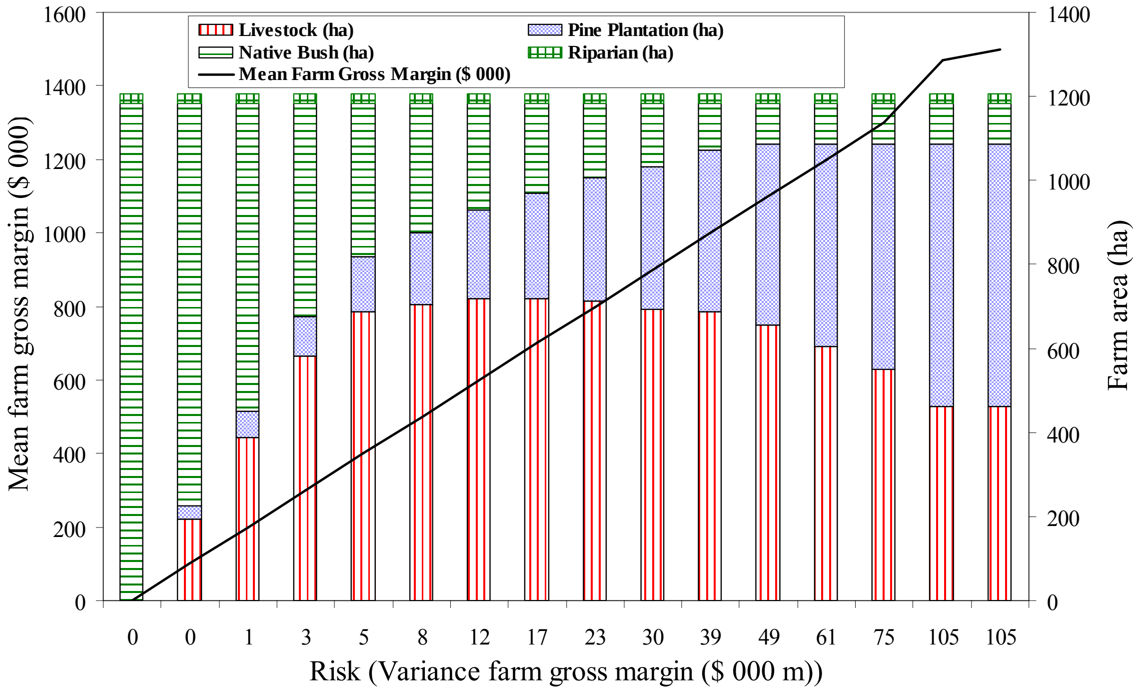

Figure 1 Risk Efficient Frontier

9000 su of sheep and beef cattle, about 460 ha of *Pinus radiata* forest plantation, 96 ha of native bush and 24 ha of riparian. Most of the data required by the risk model equations were contained in the *NZ Farmsure* EMS for the case study farm. However, additional stochastic gross margin templates were needed to calculate expected gross margin and variance of gross margins used in Equations (1) and (2), and feed intake data required by Equation (3).

The stochastic gross margins templates used in Dake and Squire (1994) were redeveloped for each farm enterprise of the case study farm. The shape of the statistical distributions of prices and yields used in the template were derived from historical data, and then modified to represent the mean gross margin data derived for the case study farm. Forestry gross margins were adapted using data from Knowles et al. (2003). The @Risk Monte Carlo simulation package (Palisade, 2001) was used to calculate mean and variance of the gross margins.

Annual pasture dry matter production and utilisation for each LMU were assessed by agri-business consultants who developed the *NZ Farmsure* EMS for the case study farm.

There is no long-term data on the statistical distribution of emissions. For the purposes of this study a CV of 20% for nitrate and GHG emissions was used. These are conservative values. For example Ledgard and Menneer (2005) reported annual nitrate losses ranging from 12-74 kg N/ha/yr over a 5 year period from dairy grazing using no fertilizer N treatment.

4. RESULTS

FSRM, described by Equations (1) to (6), has a quadratic objective function with linear constraints. It is implemented in a Microsoft Excel spreadsheet and is solved using the solver from Frontline Systems (2003). Solving FSRM for the 1,207 ha case study farm results in the risk efficient frontier shown in Figure 1. The graph indicates maximum farm gross margin and optimal farm plan obtainable for a given of level of risk (measured as the variance of farm gross margin).

A farmer may choose a position on the risk efficient graph based on their risk preference. If the farmer prefers little or no risk (and therefore accepts low farm gross margin) then the optimal farm plan is to place the whole farm into native bush and riparian. If a higher level of risk is acceptable, then the pastoral enterprises and forestry become part of the farm plan and native bush is reduced. The highest mean gross margin obtainable is approximately $1.5 m with the corresponding financial risk of $105,000,000 m (equivalent to a gross margin coefficient of variation of 22%). The corresponding optimal farm plan comprises 461 ha pastoral grazing and 626 ha forestry

Livestock carried on the farm peaks at 10,373 su at a mean farm gross margin of $1.1 m and declines to 9,800 su at the maximum mean gross margin. However, average farm stocking rate continues to increase, reaching a peak of 21.2 su/ha.

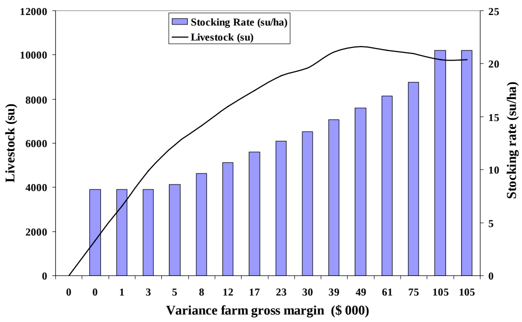

Figure 2 Pastoral Intensification

The current location of the case study farmer on the risk efficient frontier, based on livestock carried, is shown in Table 1.

Table 1 Risk efficient farm plan of case study farmer

	Location of case study farm on the risk efficient frontier	Risk efficient farmer carrying maximum livestock
Mean farm gross margin ($ 000)	800	1,100
Gross margin variance ($ 000 m)	23	49
CV of farm gross margin (%)	19%	20%
Livestock (su)	9,056	10,373
Pine plantation (ha)	294	430
Native bush (ha)	176	97
Riparian (ha)	24	24
Livestock (ha)	713	656
Mean farm GHG loss (T)	810	370
Mean farm nitrate loss (T)	9.9	12.3
Stocking Rate (su/ha)	12.7	15.8

The opportunity exists for the case study farmer to increase the livestock enterprise the farm plan. This can be done by moving up the risk efficient frontier to the point where livestock carried is highest (Table 1). The case study farmer's mean gross farm margin would increase by 38% (from $ 0.8 m to $1.1 m), and financial risk increase by 100%.

Environmental outputs of the risk efficient farm plans are shown in Figure 3. Risk efficient farmers who are content to accept a low level of farm gross margin and therefore low financial risk, or very high gross margin and therefore high risk, are net absorbers of GHG. This is because these farm plans contain a high proportion of forest or native bush which absorbs GHG. Nitrate losses increase with farm gross margins because of increasing stocking rate (intensification) are shown in Figure 2.

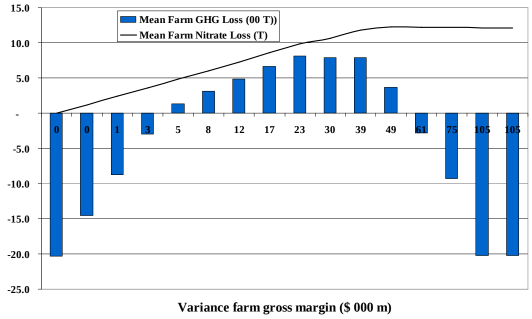

Figure 3 Total Greenhouse Gas (GHG) Loss and Nitrate Emitted by Risk Efficient Farmers.

A farmer facing the prospect of modifying their farm plan to reduce emissions to ensure that the farm is managed within a set of environmental limits would need to move along the risk efficient curve to a point that best meets the sustainable environmental targets. Financial trade-offs can then be calculated from the impact on expected farm gross margin or on gross margin variability. For example, a farmer carrying the highest level of livestock would be emitting 370 T of GHG and 12.3 T of nitrate (Figure 3). To reduce net GHG to zero the farmer would either need to reduce expected farm gross margin by replacing the livestock activities with native bush or increase financial risk by increasing the content of farm plan with Pine plantation. This demonstrates that balancing environmental and financial outcomes is not confined to only a trade-off of income for environmental credits, but also changes the level of risk.

4.1. Setting Environmental Targets

Policies to limit GHG emissions and cap nitrate losses in sensitive catchments have been suggested by regulatory bodies. Farm emissions are stochastic, varying from year-to-year due to biological processes and climatic factors. It means that a farmer who has chosen a risk efficient farm plan with the aim of meeting an environmental target would in reality breach the targets from time-to-time. The frequencies with which the emission targets are breached depend on the selected farm plan, the target level and the variability of the emission.

For example, a regulatory body may decide to use the emissions from the farmer carrying the highest level of livestock on the risk efficient frontier stock as the target for all farmers. The targets are 370 T/yr of GHG and 12.3 T/yr of nitrates.

Table 2 Reliability of Complying with Emission Targets

Mean Farm Gross Margin ($ 000)	Probability of achieving GHG target of 370 T/yr	Probability of achieving nitrate target of 12.3 T/yr
100	100%	100%
200	100%	100%
300	100%	100%
400	85%	100%
500	58%	100%
600	37%	100%
700	23%	100%
800	17%	99%
900	20%	92%
1000	24%	64%
1100	50%	50%
1200	79%	51%
1300	92%	53%
1469	98%	55%
1500	98%	55%

It can be seen that many farm plans would not comply with a 50% reliability of compliance. In the case of GHG emission, farmers earning between $0.5 m and $1 m would fail to comply. Farmers earning above $1.1 would not be able to comply above a 55% level of compliance in the case of nitrate emission.

5. CONCLUSIONS

The objective of this study is to develop a risk optimisation model that can be used by farmers to evaluate trade-offs between financial and environmental risks at the whole farm level. The environmental risks arise from the requirement to comply reliably with environmental targets. It is expected that the farmer would modify the combination of farming enterprises at the whole farm level to meet environment outcomes at minimum financial risk to the farmer.

The approach adopted in this study is that the farmer's farm plan is dictated by the farmer's position on a risk efficient frontier where farm income is maximised for the financial risk that the farmer is prepared to accept. Any point on the risk efficient frontier yields a specific farm plan and environmental outputs.

Targets set to limit environmental emissions from the farm are likely to be breached because of their stochastic nature. An environmental abatement policy should therefore also indicate both the target and the desired reliability of compliance. In this study the reliability of compliance has been calculated for GHG and nitrate emitted for points along the risk efficient frontier.

For a given level of compliance, the targets are different for each point on the risk efficient frontier. A policy that is aimed at minimising environmental risk would need to choose between having one target for all farmers, or separate targets for each farmer. Farmers who are unable to comply based on their current position on the risk efficient frontier would need to find a different position on the frontier at a cost of reduced income or an increase in financial risk.

6. ACKNOWLEDGMENTS

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