Modelling Economic Impact of Agri-environmental Policy on Dairy Farms –A Catchment Perspective

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EXTENDED ABSTRACT

Nitrogen discharge from pastoral farming is a major non-point source pollution in some Waikato water bodies. Increases in nitrogen fertilizer use and animal stocking rate of animals have the potential to increase the nitrogen discharge into water. Farms are heterogeneous in terms of their production perspective and pollution potential, which may contribute to differences in nitrogen discharge abatement cost. This article focuses on the economic and environmental impact of agri-environmental policies to abate nitrogen discharges on representative farm types in a Waikato river sub-catchment. Dexcel's WFM is used to simulate various scenarios given spatial and farm system variations.

The empirical focus is on a Waikato River Sub catchment, where dairy farming is the predominant land use. Mapping techniques are used to create representative farms within the catchment for simulation. Implementation of agri-environmental policies is likely to be a costly exercise. Hence enforcement demands careful analysis of policies. Extensive evaluation of alternative policies through experiments and monitoring is not feasible at reasonable cost within a foreseeable time span, therefore a modelling approach has considerable promise in informing policy formulations.

The objective of this paper is to explore the whole farm model as a potential policy analysis tool in a spatial context with special reference to nitrogen discharge problem from farms in Waikato. This has been achieved by integrating a nitrogen discharge function into the whole farm model. The Dexcel WFM is used for evaluation of the environmental and economic consequences of implementing different nitrogen taxes in heterogeneous farming systems in terms of soil physical variables as well as production structure. The WFM is calibrated to represent the each farming system. Taxation policies are implemented on nitrogen discharges. Three farming systems are considered. Impacts of taxes for each farm type on stocking rate, nitrogen fertiliser applied and nitrogen discharge are estimated by the optimisation module of the WFM.

Nitrogen discharge for various policies are estimated by incorporating the estimated meta model for nitrogen discharge as a penalty function in the optimisation process. Optimisation of the WFM has been performed with a specific evolutionary algorithm, a variant of a more common genetic algorithm, known as differential evolution. The strength of the heuristic optimisation adopted is the capability of generating new set of optimum activities under new constraint. This is in contrast to activity analysis, where the optimum is selected among the pre existing activities.

The results indicate the heterogeneity among farms in terms of environmental and economic impact of nitrogen policies. The magnitude of the differences in response for a policy among farming systems depends on farm size parameters such as area of farm number of animals and fertilizer use and soil physical parameters such as variability of soil type, topography which influences the input productivity and nitrogen discharge potential.

The analytical framework developed aims at general policy implications in the presence of farm heterogeneity. Efficient taxation schemes for reduction of nitrogen discharge should differentiate between farm types rather than use uniform taxes. Environmental policies may provide incentives to adopt best management practices for reducing nitrogen discharges. Future work will integrate this paper's considerations to many more soil and topographic categories and farming systems and extend the optimization routines to accommodate constraint optimisation of physical units of nitrogen discharge.

1. INTRODUCTION

Potential water quality problems posed by excess nitrogen produced in the farming sector are a major concern in Waikato. Nitrogen promotes the growth of nuisance plants and algal blooms in the river. The dairy sector is reportedly responsible for major portion of nitrogen discharges (Environment Waikato, 2007). Over a recent five year period (1997/98 to 2002/03), yearly dairy farm nitrogen fertiliser use increased 84 percent, from 68 kilograms of nitrogen per hectare to 125 kilograms per hectare. Nitrogen discharge reduction from farms can be achieved through changes in production activity, adoption of best management strategies. Changes in production can be in the form of varying the intensive or extensive margin of production. Scientific research in New Zealand has proposed many technical solutions to the nitrogen discharge such as wintering pads, reduced nitrogen fertiliser and nitrification inhibitors . However, the economic benefits of these solutions are less convincing and given the capital intensive nature or costs associated with them (Clark, 2007). Therefore voluntary uptakes of these practices are likely to be limited**.** This necessitates the exploration of using economic instruments.

Establishing the cost of nitrogen discharge reduction is essential for making informed policy decisions. Assessment of abatement costs for non-point sources poses a challenge. First best solutions to pollution control problems requires knowing each firms marginal abatement cost (MAC). The importance of modelling agri-environmental policies at disaggregated level to capture the heterogeneous nature of the physical environment and economic behaviour of farmrs revealed by (Just & Antle, 1990). Spatial information with adequate technologies and institutions can reduce the cost of controlling non-point source pollution. Therefore farm specific knowledge of abatement cost will facilitate the most efficient level of nitrogen management at catchment level. We seek to establish reasonable representation heterogeneity of farm types in order to accommodate biophysical and economic reality along with computational convenience for policy analysis.

Models for assessment of new polices need to incorporate both environmental and economic effects. Such models can help policy makers to assess trade-offs between economic and environmental objectives and thereby refine the selection of policy measures. In this paper, the use of Dexcel's Whole Farm Model (WFM) to examine the cost and effectiveness of environmental policies is illustrated with three taxation scenarios for reducing nitrogen discharges.

Capability to simulate whole dairy farm systems is a challenge that has long been recognised (Cabrera, Breuer, Hildebrand, & Letson, 2005). The complexity of dairy farms is high due to the interaction among cows, management, paddocks and climate variations.This necessitates use of models to evaluate changes in farming practices under different policies. This justifies the use of a whole farm model integrating several sub models representing the complexity.

The objective of this paper is to explore the WFM as a potential policy analysis tool in a spatial context with special reference to nitrogen discharge problem from farms in Waikato. This has been achieved by integrating a nitrogen discharge function into the WFM. WFM is used for evaluation of the environmental and economic consequences of implementing different nitrogen taxes in heterogeneous farming systems in terms of soil physical variables as well as production structure. Taxation policies are implemented on nitrogen discharges. Three farming systems are considered. Impacts of taxes for each farm type on stocking rate, nitrogen fertiliser applied and nitrogen discharge are estimated by the optimisation module of the WFM.

2. STUDY AREA AND DATA

Catchment has been considered as an appropriate spatial unit for agri-environmental policy analysis (Kampas & White, 2003). The empirical focus of this study is on nitrogen discharges in a Waikato river sub-catchment**.** The sub-catchment of this study covers the part of the Waikato River including Lakes Arapuni and Karapiro (Figure 1). Dairy farming is the predominant agricultural land use in the sub catchment occupies 72% of total agricultural land use. The extent of dairy land in the catchment is 52,877 ha, including 370 farms.

The catchments' dairy farm population parameters are derived using spatial micro-simulation. It combines geo referenced data on catchment dairy farms' soil type, topography and production potential (Milksolids) with microeconomic attributes from an economic farm survey. Representative farm systems within the catchment are derived using latent class clustering on catchment dairy farm population. Farms in the catchment are grouped according to the major soil types, topographic features and production parameters. The details of data derivation are explained at a greater detail in Ramilan, Scrimgeour, & Marsh (2007). Three farming systems in the catchment are simulated for the purpose of preliminary analysis. The farming systems are classified as moderate, extensive and intensive. Table 1. describes key variables of each farming system.

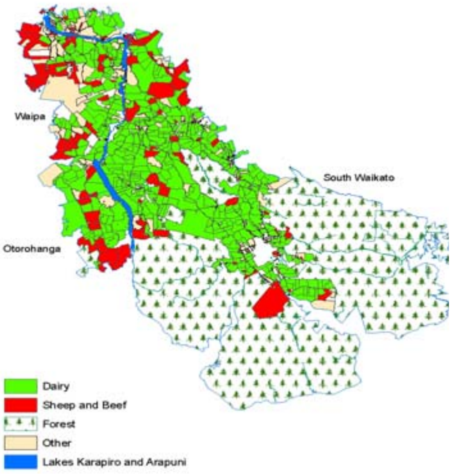

Figure1. Study area

Table 1 Means of variables of the farming systems

Variables	Moderate	Extensive	Intensive
Farm size (ha)	86	136	92
Nitrogen fertiliser (kg/ha)	121	60	290
Stocking rate(Milking cows/ha)	2.7	2.2	4.5
Annual Pasture requirement (kg/ha)	12579	9156	15000
Brought in feed (tons per cow)	0.5	0.6	2.12
Milksolids (Kg/ha)	919	688	1910
Soil type	Volcanic	Pumice	Pumice
Topography	Easy	Easy	Rolling

3. DEXCEL'S WHOLE FARM MODEL

The whole farm model (WFM) was developed by Dexcel. Dexcel is the primary research and extension arm of New Zealand's dairy industry. The WFM is a computer model, implemented using an object oriented approach based on the small talk language. It consists of climate, management, cow, paddock and economics sub models. These sub models simulate complex interactions of climate and pasture growth, cow metabolism and management regimes and resultant economic output. McCall pasture model, based on the work of McCall & Bishop-Hurley (2003), is used as the pasture model. The cow sub model used is Molly. Molly, a dynamic model, consists of differential equations describing nutrient metabolism of cows under New Zealand conditions. The economics component is similar in parameters specified in Economic Farm Survey of New Zealand Dairy farmers. The revenue of the farm is primarily derived from the sale of milksolids, where the milksolids production is multiplied by the price of kg of milksolids.

WFM is calibrated to represent the each farming system. The pasture production potential of farming system's paddocks is calibrated using the P slope parameter, which has been used as a proxy for inherent soil fertility. Cow production potential in terms of milksolids production per ha per year under different systems is calibrated by manipulating the lactation period, live weight and PV milk. PV milk is a measure of a cow's genetic production potential developed by Livestock Improvement Corporation. Dry matter response of pasture for nitrogen fertiliser application is based on the experimental results from Dexcel's Resource Efficient Dairying trials. The feed policy is fixed for each farm.

4. NITROGEN DISCHARGE FUNCTION

We explore the trade off between farm returns and nitrogen discharge restrictions. Neal(2005) studied the potential costs to New Zealand dairy farmers from the introduction of nitrate based stocking rate restrictions by restricting the stocking rate in the WFM. How ever the impact of stocking rate restrictions on nitrogen discharges has not been quantified. In order to achieve this objective, we incorporated a nitrogen discharge constraint by means of penalty function in the optimisation process. The detail of the optimisation process is explained in the next section of this paper.

Discharged nitrogen from urine and dung patches and applied fertilizer nitrogen are reported to be the major potential sources of nitrogen into water from cattle grazing systems (Ledgard & Menneer, 2005). Monaghan et al. (2007) revealed that the amount of nitrogen excreted by animals is the primary factor of nitrogen losses in terms of leaching and run off. Further they mentioned that nitrogen fertiliser indirectly contribute to nitrogen leaching by boosting the pasture production thus accommodating more number of cows on a farm. Therefore nitrogen in animal excretion, which combined with the use of nitrogen fertilizer to increase pasture production contributed to increased nitrogen discharge. Further environmental factors such as climate, soil type and topography also influence the nitrogen discharge.

The diffuse nature of agricultural nitrogen pollution and it's time lag before appearing in the water body, necessitates the use of a simulation model, to derive quantifiable measures of potential pollution. Considerable recent work focused on the central North island lake catchments has confirmed the existence of a sound knowledge of nitrogen leaching mechanisms and much of this knowledge now incorporated into models such as the Overseer(Clark, 2007). The Overseer is a nutrient budget simulation model for decision support developed by Agresearch, New Zealand's largest Crown Research Institute for agriculture.

In order to incorporate the penalty function to the optimisation process, a nitrogen discharge function is created for different farm systems identified in predominant soil and topographic parameters in the catchment (Table 1). This function is created using a meta-modelling approach. Meta modelling has been widely adopted to create nutrient discharge functions (Goetz, Schmidt, & Lehmann, 2006; Hefland & House, 1995; Martinez & Albiac, 2006). The nitrogen discharge function is estimated by simulating randomly selected 50 farms from the Dexcel's economic farm survey of 2004/05 on the Overseer nutrient budgeting model. To represent different soil types about 200 scenarios are simulated using the 2004/2005 Ruakura climate year**.** The spread of dairy farm effluent is assumed to be 20% of the farm land. The supplement and fertiliser policies are kept on par with the supplement and feriliser policies of the WFM.

Simulations of similar nature on the Overseer have been conducted by Dake, Mackay, & Manderson (2005). They fitted a full second order polynomial model in terms of stocking rate alone. We have included an additional "variable nitrogen applied to paddocks". The parameters of the nitrogen discharge function were estimated using the ordinary least squared regression procedure in Stata, data analysis and statistical software**.** Various functional forms are fitted such as second order polynomial (quadratic), logarithmic and square root functions. The data generated showed that the nitrogen discharge in terms of stocking rate and nitrogen fertiliser are best represented by a square root function. The square root functional form statistically out performed other functional forms. This is in consistent with the functional form used to estimate nitrogen discharges by Hefland and House (1995) The nitrogen discharge function is defined as follows

$$Y = \beta_o + \beta_1 N + \beta_2 SR + \beta_3 N^{0.5} + \beta_4 SR^{0.5}$$

Y= Nitrogen discharge KgN ha per year
N= Nitrogen applied to paddocks in kg ha per year
SR= Number of animals per ha.

Table 2 presents the parameters of estimated nitrogen discharge functions by soil and topographic categories.

Table 2 Estimated nitrogen discharge function by soil and topographic classes*.

Variable	Nitrogen discharge function		
Soil	Volcanic	Volcanic	Pumice
Topography	Easy	Rolling	Easy
Intercept	133.06	98.42	145.63
	(2.33)	(1.63)	(2.28)
Nitrogen	$2.73 *10^{-1}$	$2.72*10^{-1}$	$3.0 *10^{-1}$
	(4.20)	(3.97)	(4.09)
Stocking rate	49.75	38.83	54.71
	(2.51)	(1.86)	(2.47)
$N^{0.5}$	-3.5	-3.4	-3.89
	(-2.44)	(-2.27)	(2.41)
$SR^{0.5}$	-140.12	-100.72	-153.30
	(-2.03)	(-1.39)	(-1.99)
Adj R^2	0.91	0.91	0.90

5. OPTIMISATION

Optimisation of the WFM has been performed with a specific evolutionary algorithm, a variant of more common genetic algorithm, known as differential evolution (Neal 2005). It is implemented in a similar way to Mayer, Kinghorn, & Archer (2005) based on the work of Storn & Price (1997). The key aspect of genetic algorithm is the use of population of possible solutions and aspects of biological evolution, such as reproduction, selection, mutation and recombination to generate a better solution. The genetic algorithm is intialised with the generation of a population of solutions. The population consists of number of individuals and each individual is described by a chromosome. The chromosome consists of alleles. Each allele in the genotype is a real number. In our application, the genotypes represented farms and the alleles are decision variables such as input use and management. Differential evolution involves the iterative improvement of a set of solutions or genotypes based on a fitness function. The most important operations within this procedure of differential evolution adapted from Price, Stron, & Lampinen (2005),are given below. Price, Stron, & Lampinen (2005).

Differential evolution involves the iterative improvement of a set of solutions or genotypes based on a fitness function.

- Initialisation of the population by specifying boundaries on parameter values of interest
- Randomly chosen 3 population members
- Creation of mutated parent by adding the scaled vector of differences between two members with the third member
- Crossing over the mutated parent with the another member of initial population known as target vector to create a child vector. Fitness evaluates the merits of the individuals.
- If the fitness value of the child vector is lower or equal to target vector it replaces the target vector. Otherwise child vector form the new population and target vector retains its place for one more generation.

The above mentioned procedures are repeated until the optimum is located or pre specified termination criteria (number of generations) are satisfied.

The most common way of incorporating constraints into a genetic algorithm has been using penalty functions. The idea is punishing constraint violations by adding a penalty to the fitness value(Loonen, Heuberger, Bakema, & Schot, 2006).The penalty is integrated into the fitness value, therefore individuals performing well will have a higher fitness and thus more chances for survival. The penalty is specified based on price tags attached to the estimated nitrogen discharges. This penalty is then incorporated into the objective function of maximizing the economic farm surplus. The trade-offs between nitrogen discharges and economic farm surplus are derived from the results of optimisation, which yields a large range of alternatives.

6. RESULTS AND DISCUSSION

A baseline scenario for each farming system is developed to envisage the optimum combination of activities and discharge of nitrogen. Even though optimum solutions are reported here, WFM is capable of generating a range of alternative plans. This provides farmers with many options. In order to reduce the nitrogen discharge three nitrogen discharge taxes from $5 to $15 per kg of nitrogen are implemented. The strength of the heuristic optimisation adopted in this paper is the capability of generating new set of optimum activities under new constraint. This is in contrast to activity analysis, where the optimum is selected among the pre existing activities.

Nitrogen fertiliser application is capped at 200 kg/ha in the optimisation process except the intensive farming systems. Cameron, Di et al (2003) stated that nitrogen applications to pasture are most efficient when applied at rates of between 20 and 40 kg N ha and should not exceed 150 to 200 kg N/ha. Economic and environmental impact of different taxation scenarios on farming system are tabulated (Table 3). Even though the farming systems are not directly comparable due to the differences in soil and topographic characteristics, the results indicate differences among farms. The magnitude of the differences among different farming systems depends on the amount of tax. For instance the nitrogen discharge reduction (Table 4) is very costly for extensive farms. It may be those farms are already discharging low levels of nitrogen. Mean while the differences among farms at $ 15 tax are not considerable. The percent reduction of nitrogen discharges is considerably high in the moderate farms under $5 tax.

Thus efficient taxation schemes for reduction of nitrogen discharge should differentiate between farm types rather than the use uniform taxes. The effectiveness of targeted tax policies on farm nutrient discharge management also revealed in other studies as well (Hopkins, Schnitkey, & Tweeten, 1996). Targeting farms with high levels of nitrate emissions within the catchment has more potential for reducing nitrate discharges(Braden, Johnson, Bouzaher, & Miltz, 1989). However there is a trade-off between implementation difficulties associated with differentiated policies and effectiveness achieved.Differences in abatement cost indicates potential for nitrogen discharge trading policies.

Table 3. Economic and environmental impact of taxation scenarios

Scenarios	EFS*	SR*	Nitrogen discharge (KgN/ha)	Nitrogen applied (KgN/ha)
Extensive				
Base	775	1.9	37.0	200
$5 Levy	513	1.7	33.5	151
$10 Levy	379	1.6	20.3	87
$15 Levy	311	1.4	10.3	29
Moderate				
Base	1225	2.5	44.2	200
$5 Levy	983	2.2	31.5	173
$10 Levy	824	2.3	30.4	166
$15 Levy	734	2.0	12.6	59
Intensive				
Base	1893	2.4	64.3	288
$5 Levy	1522	2.6	60.1	265
$10 Levy	1271	2.5	55.7	249
$15 Levy	1104	2.0	17.9	71

*EFS- Economic farm surplus
*SR- Stocking rate

Some tax policies have less impact on certain farm systems. For instances $5 tax has less impact on moderate farms. It reveals that changing a farming system may bring cost effective discharge reductions given there is no prohibitive cost involved in such a change. De Cara, Houze, & Jayet (2005) also catergorised heterogeneity related to farm nutrient discharges into activity-data heterogeneity, emission factor heterogeneity and heterogeneity in the flexibility of substitutions between production activities. Our results too indicate such heterogeneity among farms on abatement achieved at a given tax. The heterogeneity can be attributed to activity level of the farm and discharge factors. The first source is related to farm size parameters such as area of farms number of animals, fertilizer use and feed brought in etc. The second arises from the variability of soil type, topography which influences the input productivity and discharge potential. The range of tax policies chosen here are arbitrary and for explorative purposes only. Determination of appropriate tax amount requires consideration of costs and benefits and required reduction of discharges.

Table 4. Cost of reducing nitrogen discharge in the taxation scenarios.

	Levy 5	Levy 10	Levy 15
Extensive on Pumice Easy			
Farmers cost (NZ$ /ha)	371	622	789
Farmers costs(NZ$/ KgN)	89	73	17
Moderate on Volcanic Easy			
Farmers cost (NZ$ /ha)	242	401	491
Farmers costs(NZ$/ KgN)	23	29	16
Intensive on Pumice Rolling			
Farmers cost (NZ$ /ha)	262	396	464
Farmers costs(NZ$/ KgN)	47	24	17

7. CONCLUSIONS AND IMPLICATIONS FOR FUTURE RESEARCH

An analytical framework have been developed and applied to evaluate the potential economic and environmental effects of nitrogen use policies on different farming systems

This article aims at general policy implications in the presence of farm heterogeneity. However the results from this preliminary analysis should not be considered quantitatively trivial. Efficient taxation schemes for reduction of nitrogen discharge should differentiate between farm types rather than use uniform taxes. Environmental policies may provide incentives to adopt best management practices for reducing nitrogen discharges. Future work will integrate this paper’s considerations to many more soil and topographic categories and farming systems and extend the optimization routines to accommodate constraint optimisation of physical units of nitrogen discharge. This would enable us to envisage the impact of allocating discharge limits among farms. The influence of market prices and climatic variations on the farms responses to environmental policies also need to be considered.

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