The potential cost to New Zealand dairy farmers from the introduction of nitrate-based stocking rate restrictions.

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Abstract

Introducing a stocking rate restriction is one possible course of action for regulators to improve water quality where it is affected by nitrate pollution. To determine the impact of a stocking rate restriction on a range of New Zealand dairy farms, a whole-farm model was optimised with and without a maximum stocking rate of 2.5 cows per hectare. Three farm systems, which differ by their level of feed-related capital, were examined for the changes to the optimal stocking rate and optimal level of animal milk production genetics when utility was maximised. The whole-farm model was optimised through the use of an evolutionary algorithm called differential evolution. The introduction of a stocking rate restriction would have a very large impact on the optimally organised high feed-related capital farm systems, reducing their certainty equivalent by almost half. However, there was no impact on the certainty equivalent of low feed-related capital systems.

Keywords: environmental regulation, dairy farms, whole-farm model, evolutionary algorithm

1. Introduction

The decrease in water quality of New Zealand’s waterways has been linked, in part, to the dairy industry (Crawford, 2001). Regulation of some aspects of farming activity is likely to be part of the governments’ response to solve the water quality issue. One of the proposed regulatory responses to a similar water quality problem in the EU was to limit stocking rates to 2.5 livestock units per hectare. In this paper, the impact of New Zealand introducing a similar stocking rate restriction on the incomes and optimal input choices of a range of dairy farming systems was examined.

The following two sections describe some estimates of the contribution from agriculture to nitrate leaching and proposed regulatory responses to the problem. The fourth section is used to describe the Dexcel Whole-farm Model which is used to model the impact of the stocking rate restriction. This is followed by the method for optimising the model with a genetic algorithm. The final three sections relate to the results of the restrictions, further policy considerations and concluding comments.

2. Nitrate leaching

Nitrogen, a major nutrient required for plant growth, is mobile in the soil relative to the other nutrients. Under certain conditions, nitrates can leach into groundwater. Once nitrates are in groundwater, they may be transported to other water bodies such as lakes and rivers, where it may be sourced for drinking, adversely impact human health if above certain levels. Excessive nitrates can promote excessive algal growth, reducing oxygen levels in the water and harming aquatic animals through eutrophication[1].

Crawford (2001) describes the poor quality of water in several rivers in New Zealand, where the lower reaches of several rivers had nitrate levels between three and five times the water quality guideline. Crawford (2001) also showed that groundwater nitrates are increasing in areas where dairy farming is expanding, although the levels have not yet exceeded the drinking water standard.

The likelihood and amount of nitrate leaching is strongly linked to land use. New Zealand’s total land area is close to 27 million hectares with agricultural accounting for approximately 15.5 million hectares (Statistics New Zealand, 2002). Of the agricultural uses, sheep and/or beef account for approximately 10.5 million hectares, but typical farms account for only 2-16 kg N leached per ha per year (MAF, 2002). Dairy farming accounts for 2 million hectares, but due to much higher stocking rates and fertiliser application rates, typical farms leach 18-41 kg N/ha annually (MAF, 2002). Vegetable growing farms had the highest estimated rate of leaching at 235-300 kg N/ha, but accounted for only 0.1 million hectares (MAF, 2002).

The main sources of nitrogen in the soil, which may then be leached, are through fertiliser application and animal wastes. Di and Cameron (2001) estimated that growth-synchronised application of nitrogen under high rainfall conditions lead to leaching losses of 6-17 kg nitrate/ha/year if pasture was not grazed. Unsynchronised fertiliser application increased leaching to 13-49 kg nitrate/ha/year. Animal waste from grazing dairy cattle was expected to result in leaching of approximately 33 kg nitrate/ha/year.

The leaching potential depends on soil, climate and management factors. The Waikato region is examined in detail, although many of the conclusions generalise to other areas of New Zealand. MAF (2002) used the OVERSEER model to estimate that 41 kg N/ha would be leached from a typical Waikato dairy farm that was stocked at 2.5 cows per hectare. Increased intensity (with production increasing by 20-50%), increased the model’s estimate of leaching to between 61 and 99 kg/ha, a rise of 49-140%. Hence, increased intensity (stocking rates), under the assumptions of the MAF (2002) report, leads to a more than proportionate increase in nitrate leaching.

3. Regulatory response to nitrate pollution

In New Zealand, the Resource Management Act 1991 promotes the sustainable management of natural and physical resources. It states in section 17 that “every person has a duty to avoid, remedy, or mitigate any adverse effect on the environment arising from an activity carried on by or on behalf of that person…”. Several reports have been commissioned by the government on the issue of nitrates and related issues (eg MAF, 2000; MAF, 2002; Hatton MacDonald et al., 2004), and although additional regulation is anticipated, the form of any imminent regulation is unknown.

Ireland is another country that has experienced water quality issues related to excess nitrates in regions dominated by dairy production (EC, 2002). The European Commission (EC) passed a regulation, the Nitrates Directive 1991[2], and the impact that is now anticipated in Ireland is the introduction of a maximum stocking rate of 2.5 livestock units (LU) per hectare, reduced to 2 LU/ha 4 years later (McQuinn et al., 2004). The potential impact of these limitations in Ireland was examined in Lally (2002). Farms with stocking rates greater than 2.5 LU/ha accounted for approximately 10% of dairy farms, or 2,125 dairy farms. Few farms were stocked at more than 3 LU/ha . The reduction in stocking rates to 2.5 LU/ha generally resulted in an estimated reduction in income of less than 6% (Lally, 2002).

In New Zealand, using data from Dexcel’s (2002) economic survey, it was found that 55% of Waikato dairy farms had a stocking rate over 2.5 cows per hectare, and 25% over 3 cows/ha. The overall dairy industry reported a similar distribution of stocking rates. Due to the higher average stocking rates, a limitation of 2.5 cows per hectare would be expected to adversely impact the majority of the dairy farming population.

Hatton MacDonald et al. (2004) reported on a range of economic instruments that could be considered in managing water quality in New Zealand. These instruments were considered for their potential to meet the environmental goals at lowest possible cost. This can be achieved by defining property rights and facilitating trade between firms such that the marginal cost of abatement is equated across all polluting firms.

The EU policy response has been dominated by highly prescriptive approaches. In the EU, the potential to offset agricultural nitrate leachate against urban and manufacturing sources of nutrients has not been considered, nor has the potential to offset against other agricultural industries or between firms within an industry. The lack of flexibility in favour of prescriptions such as stocking rate restrictions may be due to the ease of enforcement, as well as a low perceived benefit from the ability to offset against other firms. Another reason may be that the budgetary cost of assistance (eg production subsidies) is reduced by introducing restrictions on farming activities that also limit production. Hence, while New Zealand shares some aspects of the EU's water quality problem, the eventual regulation there may be less prescriptive than the stocking rate limitation examined in this paper due in part to the different economic and political situation.

4. Describing a whole-farm model of dairy production

In New Zealand, the group primarily responsible for research and extension is Dexcel. The primary tool used by farm systems researchers is the Whole-farm Model (WFM), and this model has been used to examine the impact of a stocking rate restriction.

Figure 1 shows a simplified schematic of the WFM (Wastney et al. 2002). The WFM treats all cows and paddocks as discrete objects, and so cows may differ in any physical aspect such as weight, genetic potential and calving date, while each paddock may be different in size and soil characteristics, and grow a different plant species. The management policies interact with the cows and paddocks on a daily time step to simulate the biophysical output. The biophysical output is then used in the economics component of the model to generate a simplified profit and loss statement, balance sheet and return on assets.

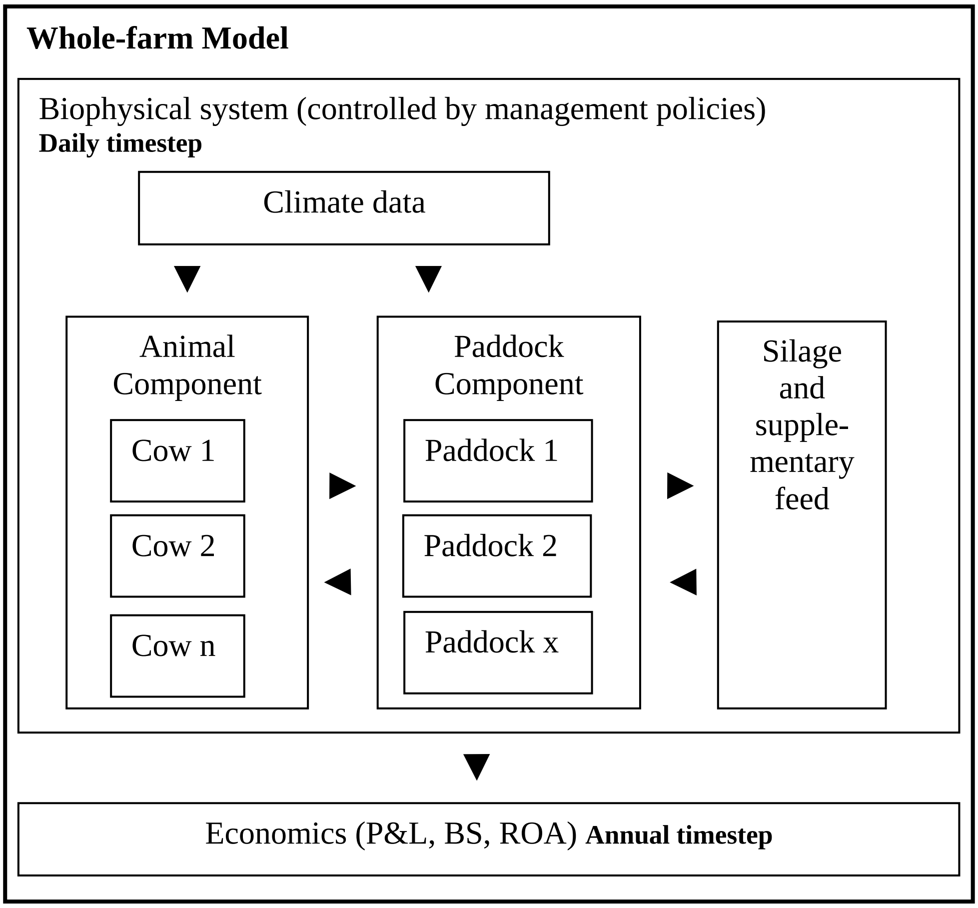

Figure 1. Whole-farm model schematic

A large proportion of costs are defined in an activity based costing framework.. The main cost drivers are the number of cows calved and the effective farm area, with default values generated through the use of economic survey data specific to a region. Constant returns to scale is assumed and Neal (2005) found this to be a reasonable assumption over a wide range of farm sizes encompassing more than half of the farms surveyed in the 2002 economic survey (Dexcel, 2002).

The WFM attempts to predict what effect variables outside the farmer’s control will have on their return, and the risk associated with that return. The major sources of risk are assumed to be weather, milk price, supplementary feed price, land appreciation rates, and the interest rate payable on borrowings. Distributions for these variables are detailed in Neal (2005). For the optimisation process, a single sample of 100 price sets was assumed to represent all possible states of nature, and was used for evaluating all farm systems during the optimisation.

Three farm systems were considered, based on the amount of feed-related capital (low, medium and high) and the associated losses associated with feeding supplementary feed. All farms were assumed to be 80 hectares in size, and begin with $1 million equity, financing the remainder of the farms assets through debt. The low feed-related capital farm used grass silage as the main supplementary feed, supplied in the paddocks by simply spreading the silage bale. Losses when feeding silage are assumed to be 30%. This compares to 25% found by Wallace and Parker (1966) in a simple system. The value of plant and machinery and dairy capital are low, and consequently the cost of repairs and maintenance is also relatively low.

The medium feed-related capital farm used a basic feedpad and a higher powered tractor to feed maize pit silage. Feed-out losses for the maize silage are lower, assumed to be 18%. The value of plant and machinery and dairy capital are higher than for the low feed-related capital farm, with a higher cost for repairs and maintenance.

In the high feed-related capital farm, larger quantities of supplements (up to 60% of animal requirements) can be fed through the year in the form of total mixed ration (TMR). Wastage was expected to be low in this system, assumed at 8% (Wallace and Parker, 1966). The value of plant and machinery and dairy capital are much higher, as are repair and maintenance costs. The key distinctions between feed-related capital levels are shown in table 1.

Table 1. Farm systems modelled

	Low feed-related capital	Medium feed-related capital	High feed-related capital
Main supplementary feed	Grass silage	Maize silage	Total mixed ration
Cost of machinery*	$87,000	$151,000	$241,000
Costs of dairy and feedpad*	$300,000	$440,000	$615,000
Losses when feeding out	30%	18%	8%
Repair and maintenance cost per ha	$135	$150	$195

*Required for standard sized farm (80 Ha)

5. Optimising the whole-farm model with an evolutionary algorithm

Evolutionary Algorithms (EA) are population-based optimisation techniques that utilise evolutionary operators such as selection, mutation and recombination. The specific EA used for the optimisation of the Dexcel WFM is Differential Evolution (DE), based on the work of Storn and Price (1997). It has previously been used in a farm model optimisation context (Mayer et al., 2005). The important features are that the algorithm performs recombination and mutation as a single step that benefits from adaptive search. Adaptive search implies that knowledge of the diversity of the current group of candidate farm systems are used in creating new farm systems to evaluate. In terms of this optimisation, the population was the group of potentially optimal farm systems under consideration. Each potential farm system was an individual within the population. Further details are given in Neal (2005).

The optimisation was firstly performed for farms at the three levels of feed-related capital, allowing any stocking rate up to 6 cows per hectare, and any level of genetic milk production potential between 30 and 40 litres peak daily milk yield. The optimisations were then performed with a maximum stocking rate of 2.5 cows per hectare. Each optimisation used a population of 60 individuals over 45 generations. The basic differential factor f was 0.4, and it was pulsed to 4 every 4th generation. The objective to be maximised was the certainty equivalent assuming unitary (constant) relative risk aversion. The certainty equivalent for one year reflects the certain amount of money that the farmer would feel is equivalent to taking on the risks and receiving the rewards of operating the farm for the year.

6. Estimated impact of a stocking rate restriction

Before the stocking rate restriction, the preferred farm system (in terms of certainty equivalent) was the high feed-related capital farm system that also had a very high optimal stocking rate. However, this system requires a much higher level of managerial ability which may explain why a minority of farms are set up in a similar way. The next most preferred system was the “medium” feed-related capital system, followed finally by the “low” system (Table 2).

Following the introduction of the stocking rate restriction, the optimal stocking rate for the “low” system was unaffected, but stocking rate reductions are required for the “medium” and “high” systems. In the “high” system, the stocking rate was reduced by 58% and a lower optimal level of milk production genetics is required. Overall, the increase in certainty equivalent falls by 49%, which was significantly less than the 58% fall in the mean return on assets (ROA). This disparity was due to the reduced exposure to financial, price and production risk at lower stocking rates. After the restriction, the preferred farm systems, ordered by certainty equivalent, were the “low”, “high” and finally the “medium” system (Table 2).

Table 2. Optimum farm systems before and after the stocking rate restriction

	Low feed-related capital	**Medium feed-related capital**		**High feed-related capital**	
			Restricted		Restricted
Certainty equivalent	136,500	161,800	112,800	227,500	115,200
% change			*-30%*		*-49%*
Mean return on assets	11.2	12.0	10.2	13.6	10.2
% change			*-15%*		*-25%*
Stocking rate, cows per ha.	2.3	4.9	2.5	6.0	2.5
% change			*-49%*		*-58%*
Milk production genetics	33	37	34	40	39
% change			*-8%*		*-2.5%*

Before the restriction, the “high” system is most profitable and uses a high level of milk production genetics (40 litres peak daily yield). The restriction leads to a fall in the optimal milk production genetics within each farm system, and the “low” system is most profitable, using lower milk production genetics (33 litres peak daily milk yield).

7. Policy considerations

Given the link between dairy farm intensity and nitrate leaching, introducing a stocking rate restriction should, ceteris paribus, reduce nitrate leaching. However, there are several complications where practical considerations reduce the effectiveness of the policy. For example, “high” systems make a large use of feed-pads, where animal effluent may be more easily trapped for application to areas of the farm in seasons where the rate of nitrate leaching is reduced, relative to a farm stocked at a lower rate that always grazes cows and cannot trap effluent. Also, farmers could meet the stocking rate restriction by purchasing more land. However, unless the farmer actually uses the additional land for grazing stock, the actual amount of nitrate leaching may be unchanged.

Unintended consequences of the restriction could include farmers attempting to recover the reduction in income by increasing pasture growth through larger applications of fertiliser. However, Di and Cameron (2001) showed that applying the same amount of fertiliser in fewer, larger amounts, or increasing the amount of fertiliser significantly increased leaching. Hence, the significant loss in income shown in this paper for some farm systems, together with uncertain benefits with regards to the actual reduction in nitrates should lead to the consideration of a wider range of solutions than simply a stocking rate restriction.

It is likely to be of benefit to farmers and the wider environment to improve the nutrient budgeting skills of dairy farmers. This is because farmers have some incentive to reduce the leaching of nutrients that could be used to grow more pasture. However, there is still the likelihood that the optimum management strategy from the farmer's point of view results in higher nitrate leaching than would be optimal from society's viewpoint because the costs of pollution are not wholly borne by the farmer. Assuming that a limit to overall nitrates allowed offsets or trading between all agricultural industries, it would be likely that dairy farmers could more cost effectively reduce their nitrate leaching than vegetable producers. The dairy farmers could use improved management practise and capital expenditure for the collection of animal wastes to reduce their potential leaching with minimal affects on production. This compares to vegetable producers who would have almost proportionate reductions in profit for a given reduction in leaching (MAF 2002).

The distributional effects of a stocking rate restriction would be uneven, and would affect the majority of farms. In particular, the profitability of highly stocked farms would be reduced very significantly. Highly stocked farms with a high level of feed-related capital may also suffer a reduction in asset values and be at increased risk of defaulting on loans (depending on their leverage). To the extent that the potential for developing high profit, highly stocked farms contribute to increases in land values, introducing the stocking rate restriction may reduce the appreciation rate of land for all farmers. A more flexible regulation, such as allowing offsets is likely to reduce the overall impact on dairy farmers. However, there are still distributional issues for dairy farmers. For example, if the area for offsets are set at catchment levels, some areas that are dominated by dairy farming, such as the Waikato, would be affected more significantly than other regions with a wider range of land uses to offset with (eg Northland).

8. Conclusions

It was found that without a stocking rate restriction, the high feed-related capital farm system provided the highest certainty equivalent. However, the certainty equivalent fell by 49% when the stocking rate restriction was introduced, and the farm system was then less profitable than the low feed-related capital farm system. The low feed-related capital farm system had an optimal stocking rate less than 2.5 cows per hectare and hence was unaffected by the restriction. For the “medium” and “high” farm systems, the percentage reduction in certainty equivalent was less than the percentage reduction in the stocking rate. This was due to the lower exposure to production, price and financial risk with lower stocking rates.

Alternative policies to a stocking rate restriction should be considered for their ability to more cost effectively meet the aim of reduced nitrates in waterways. More flexible policies may be justified because of the potential to offset against other agricultural industries as well as the existence of other management and capital-based approaches for reducing nitrate leaching on dairy farms.

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Footnotes

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[1] A certain level of phosphates are also required for large algal blooms.

[2] Council directive 91/676/EEC 'Concerning the protection of waters against pollution from agricultural sources'