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A response to Doole and Marsh (2013) article: methodological limitations in the evaluation of policies to reduce nitrate leaching from New Zealand agriculture

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A recent paper by Doole and Marsh (2013), questioned the validity of using the New Zealand Forest and Agriculture Regional Model (NZFARM) for New Zealand agri-environmental policy analysis. We respond to their critique by clearly describing the model structure, explaining the NZFARM parameterisation, calibration, and validation procedure, and presenting estimates from a series of nutrient reduction policy scenarios to highlight the utility of the model. In doing so, we demonstrate that NZFARM generates logical and intuitive results that can be used for robust agri-environmental policy decision-making.

Key words: agri-environmental policy assessment, calibration, land-use modelling, nonpoint source pollution, validation.

1. Introduction

A recent paper by Doole and Marsh (2013), hereafter 'D&M', questioned the validity of using the New Zealand Forest and Agriculture Regional Model (NZFARM) for New Zealand agri-environmental policy analysis. NZFARM is a comparative static, partial equilibrium, nonlinear, mathematical programming model of the New Zealand forest and agriculture sector. It is designed for detailed modelling of catchment-scale land uses to enable the consistent comparison of policy scenarios against a baseline by assessing relative changes in economic and environmental outputs. The key methodological issues that D&M raised are (i) the use of positive mathematical programming (PMP) for model calibration as it can produce arbitrary results and (ii) the lack of empirical model validation.

This note responds to these criticisms presented by D&M by providing detail on the model framework and demonstrating how NZFARM has used pragmatic strategies to address the very issues raised. We do this by first describing the model structure, including the use of PMP and nested

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nonlinear CET functions to address problems of overspecialisation and corner solutions. We then explain the NZFARM parameterisation, calibration and validation process. Last, we present a series of nutrient reduction policy scenarios to highlight the utility of the model. In doing so, we demonstrate that NZFARM can be used for robust agri-environmental policy analysis and generates logical and intuitive results with realistic allocations of production activities and smooth supply responses. Additional details on NZFARM can be found in the article's supplemental information (Appendix S1).

2. Structure of NZFARM

Mathematical programming models such as NZFARM have a number of features that are useful for analysing the interaction between agricultural production and the environment (Heckelei *et al.* 2012). As noted in D&M, the extension of mathematical programming models beyond farm or regional analysis can be inhibited by their ability to replicate observed patterns of production, often resulting from 'overspecialisation'. One solution is to specify cost functions using the PMP methodology, which permits the degree of spatial and production disaggregation required for environmental analysis but eliminates the need to use flexibility constraints (Howitt 1995).

NZFARM extends the general PMP formulation by nesting sets of nonlinear transformation functions (Figure 1) that represent constraints imposed by our assumptions about production technologies. We build on the foundations laid by both PMP and computable general equilibrium modelling (e.g. Dervis and Robinson 1982) and use a specified constant elasticity of transformation (CET) function that incorporates prices, quantities, average costs and a substitution elasticity. We use shadow prices from calibration constraints to obtain the difference between average and marginal returns to specify the transformation function parameters. A similar methodology is used in Johansson *et al.* (2007).

Empirical data of regional enterprise areas are used to construct a baseline where landowners determine their preferred land use, the enterprise they undertake and the management practices they employ. PMP functions represent the positively sloping marginal cost curves for the land allocation decision at the soil-type level. Three sets of nonlinear CET functions are nested under these PMP functions to allocate farm activity area and to specify the rate at which regional land uses, enterprises and management can be transformed to produce agricultural outputs. The first set allocates soil types to land use, the second set allocates land use to the enterprise areas, and the third set allocates enterprise areas to land management. This CET formulation results in a smooth response of enterprise areas to changes in relative returns among enterprises according to economic behavioural expectations of profit maximisation. This avoids

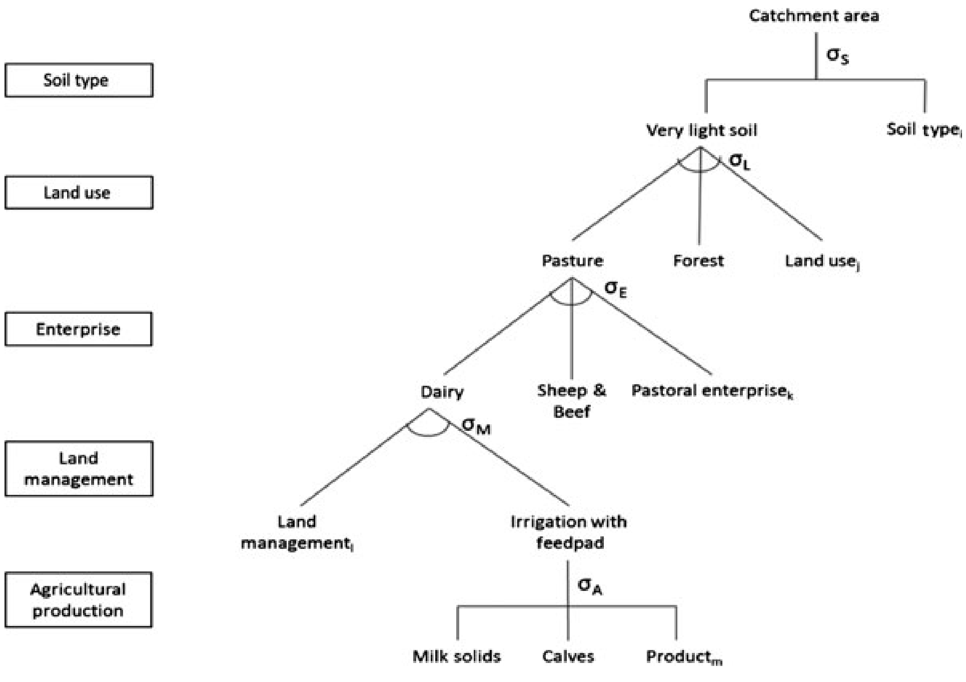

Figure 1 An example of the structure of constant elasticity of transformation (CET) function nest in New Zealand Forest and Agriculture Regional Model (NZFARM) for an irrigated dairy farm with a feed pad producing several outputs from pasture grown on very light soil.

the problems of overspecialisation and corner solutions that result from using linear activity analysis (De Frahan *et al.* 2007) as well as the problem of having to add constraints based on historical acreages (e.g. McCarl 1982). The parameters for these functions are derived from the area of each farm-level activity, the net return to each activity and an elasticity of transformation (σ).

The objective function in NZFARM maximises net revenue[1] of land-based production across the catchment subject to feasible land-use and land-management options for each combination of soil, climate and land use; agricultural production costs; output prices; and environmental factors such as soil type, water available for irrigation and any regulated environmental outputs (e.g. nutrient reduction policies) imposed on the catchment.

The 'optimal' distributions of soil type, land use, enterprise, land management and agricultural output are simultaneously determined in the nested CET framework, which is calibrated based on the shares of initial enterprise areas in each zone. These initial (baseline) enterprise areas are obtained from a detailed catchment land-use map, while the distribution of specific management systems comes from farm surveys and expert opinion from farm consultants in the relevant catchment.

[1] Net revenue (farm profit) is measured as annual earnings before interest and taxes or the revenue earned from output sales less fixed and variable farm expenses.

The key endogenous variable is the area of each activity, and landowners can adjust the mix of the land use, enterprise and land management to meet an objective (e.g. achieve nutrient reduction policy at least cost). Important exogenous variables include commodity prices, environmental constraints, water availability and technological change.

3. NZFARM parameterisation, calibration, validation and results

D&M claim that NZFARM's calibration procedure yields arbitrary outputs. They also claim that the model does not meet three necessary but not sufficient conditions for effective model validation: (i) model structure is consistent with the stylised facts of important system processes; (ii) input data are consistent with expected or reported values; and (iii) output is consistent with expected or reported values for a range of scenarios. In this section, we illustrate how NZFARM does, in fact, meet these conditions and produce logical and intuitive results.

3.1. Model data and parameterisation

NZFARM typically accounts for all major land uses and enterprises in a given catchment, including dairy, sheep, beef, forestry, arable crops, fruit and vegetables. Each enterprise requires inputs to maximise revenue from production given input costs and output prices. Options for managing farm-level nitrate (N) leaching include reducing nitrogen fertiliser application, improving irrigation efficiency, wintering off dairy cows, stream fencing, riparian planting and more.

Initial land use and enterprise areas are obtained from GIS-based land-use maps. Production yields, input costs and output prices come from agricultural consultants, enterprise experts and the literature. Nutrient losses are estimated using the latest OVERSEER version and the literature. Input data for each catchment are reviewed by catchment experts.

The CET elasticities used in Daigneault *et al.* (2012a) were land use ($\sigma_L = -2$), enterprise ($\sigma_E = -3$) and land management ($\sigma_M = -20$). The large land-management elasticity indicates that landowners are more likely to change management practices on their existing enterprise than to change land use. This finding mirrors the slow rate of land-use change in New Zealand estimated econometrically by Kerr and Olssen (2012) and Dake (2011). The CET elasticity parameter for soil (σ_S) is set at 0 as the area of a particular soil type is fixed. The parameter for agricultural production (σ_P) is also 0, implying that a given activity produces a fixed set of outputs. This parameterisation ensures that a policy scenario will not easily switch from a highly profitable enterprise (e.g. irrigated dairy) to a less profitable land use (e.g. scrub). The exception is when a policy shock is so large that changes to less productive land uses are needed to meet a policy goal.

3.2. Calibration

Many of D&M's concerns relate to the calibration process and to the degree of manipulation required for the model's baseline to reflect an observed baseline. NZFARM's use of PMP and CET functions allows the modelled land-use area to closely match the initial GIS-derived land-use areas (see appendix S1 for more detail). We find that this method results in only minor differences between observed and modelled baseline land use at the enterprise level: 3 per cent for the Manawatu catchment (Daigneault *et al*. 2012a); 2 per cent for the Hurunui–Waiau catchments (Daigneault *et al*. 2012a); and less than 1 per cent for the Hinds catchment (Daigneault *et al*. 2013). As most other key model outputs are based on fixed coefficients from the enterprise area, we find that the relative differences between the observed and calibrated values are also within the range of 5 per cent or less. Therefore, the initial land-use areas and farm-level financial budgets we use as key inputs for NZFARM calibration do provide an accurate representation of catchment economic conditions and generate a model baseline similar to observed land uses. This level of precision demonstrates that baseline calibration is minimal when sufficient effort is taken to obtain robust input data.

3.3. Validation

Empirical evidence is not always available to 'validate' a model, especially where a policy scenario has not been previously implemented, for example nutrient reduction policies or pricing agricultural GHG emissions. As this is the case with the scenarios we are assessing, we have instead

1. 'tested' the model to see whether it responds in an economically consistent manner; for example, landowners required to reduce N leaching would likely, on average, change farm-level activities to minimise net revenue impacts and that revenue impacts increase as the required reductions increase (Appendices B and C of Daigneault *et al*. 2012a);
2. checked that the model responds logically to historical changes in output prices and land-use policy; for example, dairy area expands with increases in available irrigation water and/or milk solid price (Daigneault *et al*. 2012b);
3. compared NZFARM outputs with other NZ-focused model outputs, for example both the NManager model of the Lake Rotorua catchment (Anastasiadis *et al*. 2014) and the Doole (2010) and Doole and Pannell (2011) modelling of the Waikato catchment estimated similar responses to large nutrient reduction policies as NZFARM (Daigneault *et al*. 2012a, 2013);
4. verified model estimates with local stakeholders; for example, NZFARM policy scenarios results have been reviewed by landowners, farm consultants and other researchers working in each of the modelled catchments.

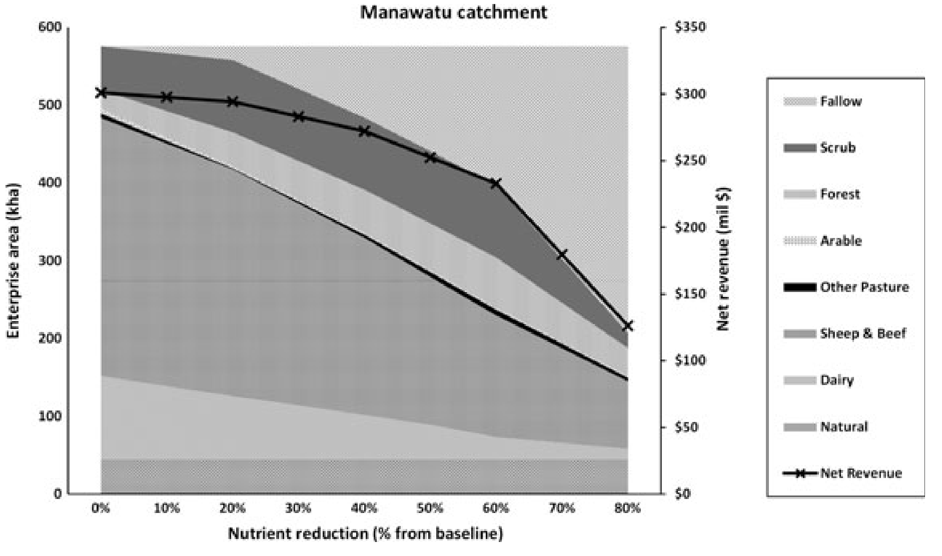

Figure 2 Changes in enterprise area ('000 ha) in response to nutrient reduction policies for the Manawatu catchment under a catchment-wide cap-and-trade programme with grandfathered NDAs (Daigneault *et al.* 2012a).

Therefore, we are confident that NZFARM produces results consistent with economic theory, with past landowner responses to policy and price shocks and with results found using other modelling approaches.

3.4. Interpretation of results

In Daigneault *et al.* (2012a), NZFARM was used to estimate the potential costs and benefits of policies designed to manage nutrients from diffuse sources, specifically N and phosphorous (P) in the Manawatu and Hurunui–Waiau catchments. The report included dozens of policy scenarios; however, in their criticism of NZFARM, D&M focus on one scenario (Policy #2a), a catchment-wide, cap-and-trade programme with grandparented[2] nutrient discharge allocations (NDA) to meet N and P reductions of 53 per cent and 61 per cent, respectively. As explained in the report, land use changed significantly because these limits could not be met with management changes alone (i.e. maximum achievable reductions with management change only were 9 per cent for N and 23 per cent for P). Therefore, land-use change is required to achieve this policy.

Figure 2 shows the distribution of land use and net revenue for a range of nutrient reduction targets (see Appendix C of Daigneault *et al.* 2012a).

[2] A Grandparent-based approach freely allocates NDAs to a given enterprise at a level of x per cent of the baseline (no policy) nutrient leaching rates, where x is the relative reduction target.

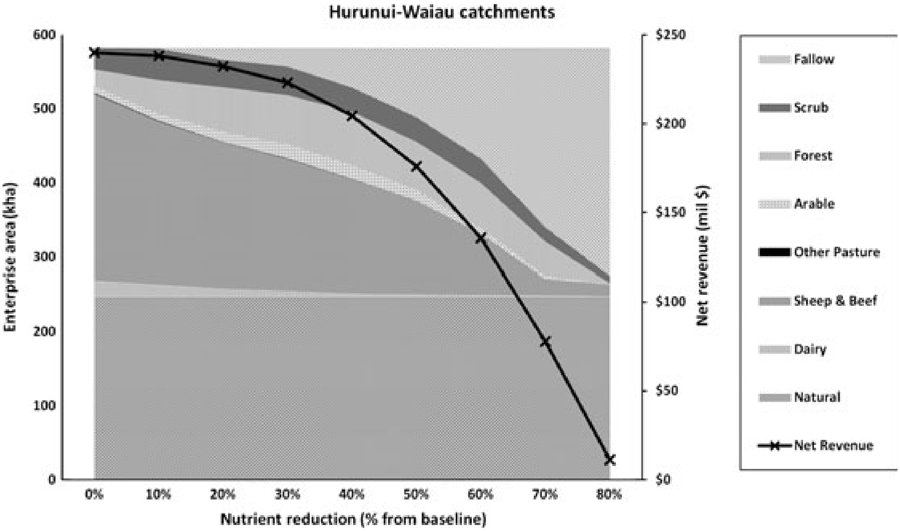

Figure 3 Changes in enterprise Area ('000 ha) in response to nutrient reduction policies for the Hurunui–Waiau catchments under a catchment-wide cap-and-trade programme with grandfathered NDAs (Daigneault *et al.* 2012a).

There are relatively small changes in land use and net revenue until the required nutrient reductions are greater than 20 per cent. With lower reduction targets, arable and forest land are still relatively profitable, but after reductions of 30 per cent, even the lower leaching forestry (4 kg N/ha/year) and scrub (2 kg N/ha/year) change to fallow[3] due to the lack of mitigation options.

Similar results were found for the Hurunui–Waiau catchments in Canterbury (Appendix B of Daigneault *et al.* 2012a), where minimal land changes to less productive uses until N reductions of about 30 per cent are required (Figure 3). Additionally, annual forestry returns are similar to sheep and beef (SNB), so SNB converts to forestry as it leaches fewer nutrients without resulting in significant change in net revenue. Therefore, catchment revenues remain relatively stable until higher nutrient reductions are imposed. Again, costs increase because there are few mitigation technologies available to meet more stringent nutrient reduction policies.

A similar study in the Hinds catchment (Figure 4) shows results in which a larger area of dairy and irrigated enterprises provides more mitigation opportunities (Daigneault *et al.* 2013). Unlike the results shown in Figures 2 and 3, large land-use changes do not occur until nutrient reduction goals of 60 per cent or more are required. This result indicates that the availability of more mitigation options affects the policy response and demonstrates that

[3] In this analysis, fallow land in NZFARM serves as a residual or 'backstop' mitigation as it is assumed to leach 0 kg N/ha and lose 0 kg P/ha over the long run.

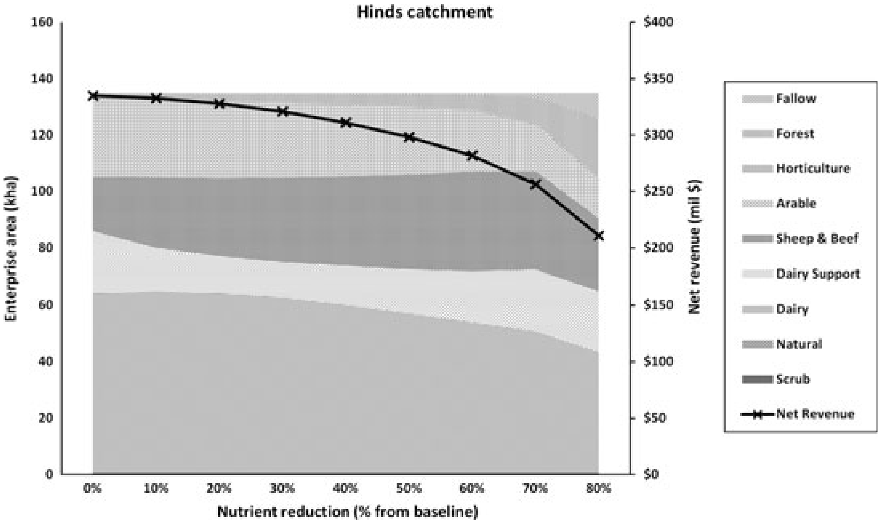

Figure 4 Changes in enterprise Area ('000 ha) in response to nutrient reduction policies for the Hinds catchment under a catchment-wide cap-and-trade programme with grandfathered NDAs (Daigneault *et al.* 2013).

NZFARM does produce results that are consistent with neo-classical economic theory.

4. Concluding remarks

NZFARM was developed to consistently compare the relative impacts of agri-environmental policies on landowners at the catchment scale, forming part of the evidence to evaluate the 'best' policy to pursue. Its model structure and calibration framework uses PMP and nested nonlinear CET functions to address problems of overspecialisation and corner solutions. This approach permits the degree of spatial and production disaggregation required for robust agri-environmental policy analysis without imposing flexibility constraints.

Land use is constrained based on initial enterprise areas, with feasible land-use and management choices for each soil/climate/land-use combination. Of course, large policy shocks often lead to greater land-use change as the model optimises against these stringent constraints. It is not realistic to calibrate this type of model to a given year and then to validate against data from other years, as suggested by D&M. Instead, NZFARM results are validated through ensuring the results are consistent with rational behaviour, verifying responses against historical price or policy shocks, comparing results with other models and sharing results with stakeholders for critique and confirmation that they are plausible and realistic.

We show that NZFARM does provide an economically consistent and robust approach to evaluate policy and resource-constraint impacts on land use, and that the pragmatic strategies outlined by D&M to address the issues with mathematical programming have already been undertaken. The next practical step for comparing models that evaluate policy would be to use the same input data in multiple models to assess the same policy. Care should also be taken when communicating model results to inform robust policy and ensure they are not misinterpreted or taken out of context.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1 Structure, parameterisation, calibration and verification of NZFARM, a mathematical programming approach to evaluate policies to reduce nitrate leaching in New Zealand.