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Use of positive mathematical programming invalidates the application of the *NZFARM* model

Response to Daigneault *et al.* (2014)

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NZFARM is a mathematical programming model that has been broadly applied throughout New Zealand to investigate different environmental issues (Daigneault *et al.* 2012). It uses optimisation methods to determine how land use and land management could be expected to change under different circumstances, such as when alternative targets for reducing nutrient outflows from agricultural land are simulated. The various regions and issues to which it has been applied are detailed in Daigneault *et al.* (2014), hereafter DG&S.

Doole and Marsh (2014) have recently highlighted how this framework produces arbitrary and biased predictions due to its reliance on positive mathematical programming (PMP) (Howitt 1995) for calibrating the baseline land-use allocation.[1] Their concern rests around five key issues (Doole and Marsh 2014):

1. There is an infinite number of sets of calibration function parameters that can generate the observed baseline land use (Heckelei and Wolff 2003).
2. Calibration does not use any information on how the relative value of land uses changes as land-use allocation moves away from the observed baseline (Heckelei and Britz 2000, 2005; Heckelei 2002). Each one of the infinite sets of calibration function parameters—from which one is arbitrarily selected to calibrate the model to baseline data—yields a different policy response from the calibrated model. Thus, the way in

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[1] Throughout this document, in line with the literature, the term PMP is used to refer to the use of shadow prices from calibration constraints to help calibrate a land-use optimisation model to a reported baseline.

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which the model performs outside of the calibrated scenario is completely unpredictable (Heckelei 2002).
3. The theoretical basis of PMP is, "weak or at least not apparent" (Heckelei and Wolff 2003, p. 28).
4. The relative value of alternative land-use activities is altered through the introduction of calibration functions.
5. Functional forms used for calibration functions in PMP implementations are generally ad-hoc and difficult to justify (Heckelei and Wolff 2003; Heckelei *et al*. 2012).

Doole and Marsh (2014) also provide specific examples of counter-intuitive results generated from *NZFARM*, which are symptomatic of problems with calibration of a land-use optimisation model.

We are pleased that DG&S have responded to these criticisms. Debate on these issues is essential, as the *NZFARM* framework has the potential to provide important insights into diverse issues pertaining to land management in New Zealand. There has been much intellectual effort and public investment put into this model; thus, it is timely and valuable to reflect on its structure. Moreover, if such costly decisions as those regarding water quality improvement are to be made based, at least partly, on output from models such as *NZFARM*, it is important that these frameworks are theoretically sound.

Importantly for readers, the response of DG&S describes the key reliance of the *NZFARM* model on PMP for model calibration. A key statement from their note is that, "We use shadow prices from calibration constraints to obtain the difference between average and marginal returns to specify the transformation function parameters" (p. 282). This is noteworthy because it is this approach to PMP that has now been invalidated after a decade of theoretical and applied research (Heckelei 2002; Heckelei *et al*. 2012). Indeed, the use of shadow prices from calibration constraints is, "neither necessary nor advisable as shadow prices of resource constraints are set arbitrarily by this procedure" (Heckelei *et al*. 2012, p. 111). Accordingly, "[e]xtremely unreasonable supply responses have been generated in the past with oversimplified PMP specifications" (Heckelei and Britz 2005, p. 61). These developments are disregarded in the response of DG&S, where no reaction to the five key issues listed in Doole and Marsh (2014)—stated above for convenience—is provided. This failure to address more than 10 years of theoretical work in this area will give little confidence to those who base decisions on the output of *NZFARM*, in that counter-intuitive results can easily be generated and detrimentally impact understanding of key processes. Examples of such findings from *NZFARM* are summarised in Doole and Marsh (2014), although it is recognised that multiple findings that fit economic intuition have also been generated.

Another reason that PMP should be removed from *NZFARM* is that this would appear to have a low opportunity cost. Daigneault *et al*. (2014) explain

that *NZFARM* calibrates within 1–3% of the reported baseline without PMP, given the accuracy of the underlying farm level data. This would appear to support the case for not using PMP, as its omission would have little impact on model calibration, while also allowing the modellers to separate themselves from a wealth of research that has invalidated the application of this technique.

An added benefit of removing PMP from land-use optimisation models is that the arbitrary non-linear functions used within these specifications (Heckelei *et al*. 2012)—such as the CET functions used in NZFARM—are no longer present, increasing the chance that the modelling team and people outside this team can understand what is happening within the model. This is aided by the fact that most equations in a land-use optimisation model are linear, and thus the reasons underlying the behaviour of a given model run are typically more easily understood.

Heckelei *et al*. (2012) recently reviewed a large number of land-use optimisation models used throughout the world. These authors observed that the calibration methods applied within *NZFARM*—involving shadow prices estimated from calibration constraints—have been "abandoned" (p. 121). Accordingly, *NZFARM* should be revised to bring it in line with the current state of the art, where theory has driven the development of more meaningful approaches to model calibration. Ways in which this could be done are listed in Doole and Marsh (2014). To be effective, it is critical for economists to reflect continually on their practice, especially in light of theoretical developments, and refine their practice accordingly. This specific case is illustrative, in that continued reliance on a disproven technique has invalidated the use of a potentially powerful model. Indeed, while *NZFARM* continues to use positive mathematical programming for calibration, it will continue to provide arbitrary and biased predictions.

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