Mathematical programming options for farm optimisation: A recommendation

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General Comments

Based on the results presented in "*Representing Weather-Year Variation in Whole-Farm Optimisation Models: Options and Importance*" (Young *et al* 2023) and the authors' experiences we provide some general insights into the optimal choice of modelling frameworks for different tasks.

The three different optimisation modelling frameworks examined are:

(i) Deterministic static equilibrium programming (SE) (e.g. Kingwell and Pannell, 1987). SE represents the farming system with a single discrete state. Representing a farm system as a single state requires use of expected inputs and outputs (e.g. the wheat yield is the average of all years). It assumes every year is the same and the finishing state equals the starting state. Thus, only strategic (long term) management is represented and management does not change between years because there is only one branch of the decision tree being represented.

(ii) Single year discrete stochastic programming (DSP) (e.g. Kingwell et al., 1991). DSP represents the farm system with multiple discrete states where each state represents a different weather-year that can have separate inputs to reflect different prices and weather conditions. All states begin from a common point that is determined by the weighted average of the end of all the weather-years, but then separate at various nodes during the production year to unveil the particular nature of that weather-year. Once a weather-year has been identified, subsequent decisions can be differentiated based on the known information about that given weather-year. For example, one node is the start of the growing season or 'break of season'. If that start is what is known colloquially as an 'early break', then after that starting point those types of weather-years can be managed differently to weather-years where the break occurs later. For example, in an early break it may be optimal to crop more area and run a higher stocking rate and vice-versa for a late break, although these decisions can only be made after the break of season is known. However, at the break of the season the subsequent conditions are uncertain (e.g. 30% chance of a poor spring and a 70% chance of a good spring). Thus, the decisions made at the break of season must factor in future uncertainty about the spring conditions. DSP examines each possible outcome and its probability to determine the optimal decisions. These decisions are a suite of tactical adjustments made at each node that complement or adjust an overarching farm management strategy.

(iii) Multi-year discrete stochastic programming (SQ) (Xie and Huang, 2018). SQ is similar to DSP with the difference being that the discrete states represent a sequence of weather-years in equilibrium rather than a single year in equilibrium. Optimisation of management within the sequence of weather years fully accounts for the temporal effects of management change between years. In AFO, the production data in the SQ is the same as the DSP for the individual weather-years. The difference is that the SQ framework more accurately represents carryover management implications from the previous year. For example, if stock were sold in the previous year the current year would start from a destocked position.

Firstly, the reader may be left with the impression that the SE framework is inferior, albeit being simpler to use. However, it should be noted that although the SE framework does not represent uncertainty or variation in weather-years or prices it still has the capacity to represent the biology and economics of a farming system in a very detailed way and therefore provides more accurate results than gross margins or partial budgets.

The importance of including weather variation in whole-farm bioeconomic modelling depends on factors including:

(i) The purpose of the analysis e.g. policy-making, farm planning, research prioritisation, innovation evaluation and aiding farm decision-making. For example, for a policy analysis where the focus is on ascertaining the general directional impacts on farm profit, the extra detail has less value because policy-makers are generally interested in the strategic management rather than tactical adjustments. Similarly, for assessment of some innovations, the relative difference in profit with and without the innovation is likely to be somewhat similar across the optimisation frameworks, so the detail of required farm management changes may be unnecessary to aid the decision about whether or not the innovation is worthwhile. That said, the magnitude of the profit difference associated with each optimisation framework, with and without the innovation, may be different. Where innovation users e.g. farmers or advisers, want to know more exactly the magnitude of increased profits derived from use of the innovation then a framework that describes weather-year variation may be warranted. Furthermore, if the purpose of the analysis is to provide advice to farmers on optimal management within particular weather-years regarding the innovation, then the extra detail provided by the SQ or DSP models may be vitally important. Janssen and van Ittersum (2007) and Reidsma et al. (2018) both similarly comment how the intended end use of a model is important for the assumptions made in a model, and the required interaction with stakeholders.

(ii) The topic of the analysis (e.g. climate change, price change, livestock productivity, pasture varieties, labour supply). For example, if the topic of the analysis is climate change, then the credibility of the analyses hinges on accurately representing changes in the probability distribution of weather-years or the types of weather-years; and how optimal farm management varies in the face of those changes. In this case, applying the DSP or SQ frameworks, rather than the SE framework would be essential.

(iii) The farm scenario being analysed e.g. financial circumstances. For example, in a finance-constrained environment it may be important to reflect the impact of last year on the opening cash balance for the current year. Hence, using the SQ model is pertinent, whereas in a region that is well established with low farm debt levels, the extra detail and time required for a SQ analysis may be unwarranted.

Overall, even though representing uncertainty in farm optimisation modelling requires additional user skill and time, the results provided can be substantially different from an equivalent steady state framework. Thus, in many cases the benefits of more accurate results can quickly outweigh the added cost. In the farming system outlined in this research paper, modelling without proper representation of tactical management results in foregone profit of $144 573 per year. Additionally, modern programming languages make it simple to build models with capacity to customise the level of detail represented in any individual application. Designing models that incorporate this feature allows the detail of the model to match that required for a meaningful analysis. It is also worth noting that the representation of weather-year variation becomes even more important if a farmer's attitude to risk needs to be represented; noting that a risk averse farmer's optimal management is likely to change due to weather variation.