Integrated whole-farm modelling — an application for policy analysis of climate change adaptation

Research Paper 2012.6

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Economics and Policy Research Branch
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Paper presented at the 2012 annual conference of the Australian Agricultural and Research Economics Society
7–10 February, Fremantle, Western Australia

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March 2012

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## Contents

- Acknowledgement 5
- Abstract 6
- 1. Introduction 7
- 2. Whole-farm models of farming systems in Victoria 7
  - 2.1 Cropping component 8
  - 2.2 Livestock component 8
- 3. Integrating EPRB whole-farm models 9
  - 3.1 Integrated model structure 9
  - 3.2 Solution process 10
- 4. An illustrative application 11
  - 4.1 Impacts of climate change on regional agriculture 12
  - 4.2 Potential benefits of adaptation options 13
  - 4.3 Results and discussion 13
- 5. Conclusions 16
- References 17
- Appendix 1 19
- Appendix 2 22
Acknowledgement

The authors would like to thank Dr Craig Beverly of the Victorian Department of Primary Industries and Dr Jason Crean of NSW Department of Trade and Investment, for providing helpful comments on a draft of this paper.

Acknowledgement also goes to Dr Richard Eckard, Dr Brendan Cullen and Dr Kithsiri Dassanayake of the School of Land and Environment, University of Melbourne, as well as to Dr Garry O’Leary, Esther Liu and Prof. Bill Malcolm of the Victorian Department of Primary Industries, who all rendered valuable assistance to the research underpinning this paper.

The authors gratefully appreciate the encouragement and support rendered by Dr Deborah Peterson, Ms Deirdre Rose and Mr Gavan Dwyer of the Policy and Strategy Group within the Victorian Department of Primary Industries.

Any errors remaining in the paper are the authors’ responsibility. Moreover, the views expressed in this paper are those of the authors and do not necessarily reflect the views of their affiliated organisations.
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Abstract

This paper describes an integrated modelling approach suitable for analysing a wide range of policy, economic and environmental issues where spatial heterogeneity is important. The approach involves overlaying whole-farm models onto GIS map layers of land use, soil, climate and topographic information. The integration is implemented through a Matlab® platform connected to a suite of Excel® based farm models. This approach enables flexible, efficient data processing and scenario analysis. The integrated modelling platform can be used to assess Victoria-wide and regional farm-level impacts of climate and weather changes, policies, market developments and new technologies. It supports comparative assessments of the ‘before’ and ‘after’ scenarios, but not the identification of farm adjustment paths over time. To demonstrate its functionality, we present an application that evaluates possible consequences of technological adaptation under a common climate change scenario in affecting farming systems and land-use patterns in Victoria.

Keywords: Whole-farm modelling, spatial land use analysis, GIS, mathematical optimisation, climate change
1. Introduction

The Victorian Department of Primary Industries (DPI), through its Economics and Policy Research Branch (EPRB), maintains a suite of whole-farm models representing major farming systems in the State. The models have been developed by different staff at different times over the past two decades. As such, they do not have a uniform structure and are based on separate databases. For further background on the development of approaches to farm modelling, see Appendix 1.

This paper reports a methodology to developing an integrated whole-farm modelling platform that can manage spatial heterogeneity. GIS layers are used to link whole-farm models to the regions that the models represent. This type of integration is helpful in analysing policy issues that affect farming practices across the State, such as climate change adaptation and land use change. The paper also includes an application of the integrated modelling platform to test its functionality, on a climate change research issue.

The rest of the paper is structured as follows. Section 2 provides a general description of the whole-farm models maintained by the DPI. The methodology adopted to integrate them is explained in section 3. An application of the integrated framework to a climate change scenario is reported in section 4. Section 5 concludes the paper with a discussion of model limitations and proposals for further model development. History and different approaches to modelling farm systems, and a complete inventory of the regional whole-farm models are included in Appendices.

2. Whole-farm models of farming systems in Victoria

Dryland dairy and broadacre (grain, sheep and beef) farming accounts for roughly 50 per cent of the total annual output value of agriculture in Victoria (ABS, 2006). Reflecting the economic significance of these activities, the EPRB whole-farm models are primarily concerned with broadacre and dairy farming in different dryland regions. Table 1 presents the list of whole-farm models maintained by the EPRB. Two types of cropping model, PRISM and EMAR, exist for capturing regional differences in crop farming. CAB model, is used to represent livestock production. An inventory of these models, including their full names, regions represented and other details, is given in Appendix 2.

EPRB also maintains a separate model, namely the Water Policy Model (see Eigenraam et al. 2003), to represent agricultural activities and water use across irrigation districts of the Northern Victorian Irrigation Region. This model has not been included in the integrated modelling platform.

Whole-farm model solutions are based on the maximisation of whole-farm gross margin, generating estimates of the optimal activity mix in terms of crop rotation, livestock stocking rate and feed mix. Optimal activity mix can be estimated for specific rainfall, price and technology conditions. These models are applicable for evaluating farming practice changes associated with technology adoption, changing crop and pasture cultivars, management practice improvement and policy change.

Data for the models come from various sources. Prices of farm inputs and outputs are sourced from the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) and DPI. All commodity price data are averaged over five-years. Yield of crops, pasture and livestock products, and rates of farm input use are calibrated using local industry intelligence from DPI researchers and extension staff. Yield and input use estimates are region-specific and are assumed to remain stable over time.

The linear programming (LP) framework for the EPRB whole-farm models comprises an objective function for maximising whole-farm gross margin and a set of constraints on farming activity and resource availability such as land areas for particular farm systems. An exogenous change to the farming system is effected through ‘shocking’ specific model parameters. The impacts of a system change are measured by comparing model variables between the model runs with and without the parameter shock.
Table 1: EPRB whole-farm models

<table>
<thead>
<tr>
<th>Name of the model</th>
<th>Farming system represented</th>
<th>Region represented</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRISM–NC</td>
<td>Mixed grain/sheep</td>
<td>North-central</td>
</tr>
<tr>
<td>PRISM–NE</td>
<td>Mixed grain/sheep</td>
<td>North East</td>
</tr>
<tr>
<td>EMAR–Mallee</td>
<td>Mixed grain/sheep</td>
<td>Mallee</td>
</tr>
<tr>
<td>EMAR–Wimmera</td>
<td>Grains</td>
<td>Wimmera</td>
</tr>
<tr>
<td>Dairy CAB–Gippsland</td>
<td>Dairy cattle</td>
<td>Gippsland</td>
</tr>
<tr>
<td>Dairy CAB–SW</td>
<td>Dairy cattle</td>
<td>South West</td>
</tr>
<tr>
<td>Beef CAB–Gippsland</td>
<td>Beef cattle</td>
<td>Gippsland</td>
</tr>
<tr>
<td>Beef CAB–SW</td>
<td>Beef cattle</td>
<td>South West</td>
</tr>
<tr>
<td>Beef CAB–NE/GV</td>
<td>Beef cattle</td>
<td>North East/Goulburn Valley</td>
</tr>
<tr>
<td>Sheep CAB–Wimmera</td>
<td>Sheep</td>
<td>Wimmera</td>
</tr>
<tr>
<td>Sheep CAB–SW</td>
<td>Sheep</td>
<td>South West</td>
</tr>
<tr>
<td>Sheep CAB–NE/GV</td>
<td>Sheep</td>
<td>North East/Goulburn Valley</td>
</tr>
</tbody>
</table>

All the EPRB whole-farm models are coded in Excel® spreadsheets, with the LP matrices optimised using the add-in software ‘What’s Best®’. Model validation is based on comparing model estimates with actual farm data on crop rotation practices, crop yields, stocking rates and crop areas. Below is a brief account of the cropping and livestock components in these models.

2.1 Cropping component

For broadacre enterprises, the crop and crop–pasture rotation sequences are based on a combination of annual pasture, cereal crops (wheat, barley, oats and triticale), pulse crops (lupins, field peas, chickpeas and lentils) and oilseed crops (canola). The set of crops included for rotation varies across regions.

The key to determining optimal crop rotation is the impact on crop yields. For specific crops, the yield rate depends on the paddock history of the two previous years. In addition, the crop yield is dependent on the history of weed, disease, nitrogen and moisture status of soil. The dependence of yield on rainfall is modelled following the ‘water use efficiency’ (WUE) approach suggested by French and Schultz (1984) and Fischer (1979).

For the annual models to represent inter-seasonal rotation, it is assumed that all crops of the rotation are simultaneously grown on certain proportions of the farm land area and the crop on each proportion of the land is rotated from year to year. This modelling setup is similar to that of MIDAS (Kingwell and Pannell 1987).

2.2 Livestock component

Sheep enterprises are self-replacing Merino ewes, Dorset over Merino ewes (or first-cross lamb), first-cross ewes (or second-cross lamb) and Merino wethers. Beef cattle enterprises are beef vealer production, store weaner production, store steer production, yearling steer production, bullock production and a backgrounding operation. Dairy cattle production is operated by winter and autumn calving enterprises with the ability to choose seasonal or split calving in any month.

Modelling livestock production is based on monthly feed budgets. Optimal stocking rates are determined under the criterion of least-cost feed mix. Under a demand-driven approach, feed requirements per animal are fixed at levels dependent on the production per animal and the monthly body weight pattern.

The energy requirements of animals are calculated in relation to the monthly flock/herd structure, body weights, weight changes and physiological status of animals. Energy demand is assumed to be first met by metabolisable energy available from the pasture, either within the month or after ‘carrying-over’ to the following month while allowing for certain decline in pasture quantity and quality. For the summer period when there is no active pasture growth, energy available from stubble is used to feed livestock in the mixed farming systems. Hay and feed grain may also be used to fill any feed gaps as necessary.
During this period, the feed intake of sheep is restricted to their dry matter intake capacity to account for low energy concentrations in hay and stubble.

Subject to matching the energy demand patterns of the sheep enterprises with the energy supply from pasture and stubble on a monthly basis, modelling solutions determine the most profitable animal enterprise and the number of animals that the farm system can carry.

Potential annual dry matter production from pasture is estimated as a function of the growing season rainfall (French 1992). This potential production is further adjusted to reflect local system conditions to arrive at region-specific pasture production levels. Estimates on percentage monthly distributions of pasture production in the region and monthly energy contents are used to derive the monthly availability of dry matter and energy. Estimates on average pasture utilisation are used to convert the amount of energy and nutrients from pasture into animal intake.

3. Integrating EPRB whole-farm models

We integrated all 12 EPRB regional whole-farm models into a Victoria-wide framework using the Matlab® software (The MathWorks 2000), and linked this framework to Geographic Information System (GIS) map layers. The integration structure and the solution process are as follows.

3.1 Integrated model structure

The design of model integration seeks to preserve transparency of the whole-farm models. To this end, we keep the original Excel files containing the LP matrices and all the model parameters (Figure 1a), and create a Matlab interface to read these matrices and perform model optimisation.

This integration procedure is largely automated, requiring minimal intervention by the user. Yet it provides the clarity and transparency necessary to facilitate communication between modellers and regional staff when updating data, developing scenarios, calibrating shocks and interpreting results.

Under the integrated framework, the LP matrix of each whole-farm model remains to be solved independently. For each region, the resultant optimised whole-farm gross margins are aggregated using the relevant GIS raster map layers (Figure 1b). This aggregation procedure can then produce a farm profit map of all agricultural regions in Victoria (Figure 1c).

The mapping of farm system changes to Victoria-wide production impacts is the most significant improvement to the modelling procedure, which greatly enhances the capability of whole-farm modelling to undertake policy analysis in a spatial context and to visualise modelling results for improved communication with stakeholders. The GIS maps can be used to provide detailed modelling results at sub-region level, capturing spatial variability within and across regions.
Specifically, the GIS raster map layers are read in to Matlab as matrices and saved in a binary '*.mat' file. At the moment, only costs and prices, costs and prices for biophysical effects, technical and environmental change, and biophysical change are read into Matlab as matrices. The objective function coefficients from the corresponding whole-farm models. Solution of the LP models produces farm profit maps (c).

3.2 Solution process

The solution process is centred on the Matlab code, which is used to (i) read the existing GIS files; (ii) solve the LP matrices; and (iii) assign results to individual regions (Figure 2).

Specifically, the GIS raster map layers are read into Matlab as matrices and saved in a binary '*.mat' file. At the moment, only the map layers of land use and regional boundaries are stored and used. Other map layers such as rainfall, soil type or topography can be added in the future.

An Excel file is created to contain model names that are read into the Matlab workspace. Any subset of the 12 whole-farm models can be integrated in this way, with the name list directing Matlab to read the relevant LP matrices, vector of constraints and vector of objective function coefficients from the corresponding whole-farm models.
Figure 2: Representation of the solution process

When solving the LP models, the relevant '*.mat' files are loaded. Results from individual models are then aggregated by region, or by sector, or across the whole state. For each farming system within a particular region, the relative contribution (i.e. the weighting factor for aggregation) is derived using crop and pasture area statistics, livestock numbers and production value estimates published by the ABS (2006) — the most recent agricultural census of which small area data have been released. For each region, the total gross margin is calculated as a product of the per hectare gross margin for a specific farming system, the number of map grids in the region, and the standard grid size (i.e. area in hectares).

The final step is to save the LP data, LP solutions and profit maps into a binary '*.mat' file. Accordingly, a single file is created to store all the relevant modelling information for each scenario run. Between different scenarios runs, the binary files will have exactly the same structure — which facilitates the extraction, manipulation and batch processing of the stored information in these binary files.

Model shocks can be designed in numerous flexible ways. One way is to adjust activity budgets (also called ‘objective values’) to represent cost and price changes. Another way is to adjust resource constraints to represent regulatory impacts on land use or availability of other natural resources. Yet another way is to adjust matrix coefficients to represent technological and environmental impacts on farm system operations. It is also possible to adjust model parameters representing biophysical aspects of the farming system, such as when assessing the impact of introducing a high-yielding crop variety.

4. An illustrative application

The integrated platform is applied to climate change adaptation. This was done in two steps. First, we estimated the impact of climate change on dryland farming systems in Victoria. This was to represent a scenario where no adaptation response occurs. Second, we assessed the benefit of adapted farming systems in a scenario where farmers take up certain adaptation options recommended by DPI scientists. This was to represent the outcome of DPI research and extension services promoting technological opportunities to mitigate possible adverse impacts of climate change on Victoria’s agriculture.
4.1 Impacts of climate change on regional agriculture

Some scientists projected that the temperature in regional Victoria would likely increase as a result of climate change (Soste et al. 2011). Moreover, rainfall was projected to decrease and the seasonality of rainfall and temperature to shift in some areas of the state. If such projections materialise, the temperature rise and rainfall reduction could hamper crop growth and yield.

On the other hand, the elevation of atmospheric carbon dioxide (CO2) concentration along with a temperature rise could stimulate photosynthesis and improve nutrient and water use efficiency in growing crops and pasture (Tostovrsnik et al. 2010). Accordingly, climate change could bring positive effects on vegetative growth that offset the negative impacts of lower rainfall in the crop growing season. However, if the climate is to become increasingly dry and hot, the net efficiency of plant growth would eventually reach a threshold and decline thereafter (O’Leary et al. 2011).

A number of studies produced scientific evidence about the potential impacts of climate change on plant growth. According to the study by Sheehy et al. 2005, rice yields would increase by 0.5 t/ha (ton per hectare) for every 75 ppm (parts per million) increase in CO2 concentration, and decrease by 0.6 t/ha for every one Celsius degree increase in temperature. The study by Howden et al. (2008) suggested that, in Australia, a 10 per cent rainfall reduction would cancel out the CO2-induced fertilisation benefits in livestock regions subject to modest net drying over time.

We primarily used the Intergovernmental Panel on Climate Change (IPCC 2001) ‘2050 High’ emissions (also called ‘A1Fi’) scenario for modelling. However, compatible regional climate impact estimates were not all available for this scenario. Therefore, as suggested by Cullen (2011, pers. com.), we also drew on the ‘2070 Medium’ scenario (also called ‘A1B’) when sourcing data on climate impacts for a few regions under study.

Estimates of the potential impacts associated with these climate change scenarios on crops and pasture in each region were collected from various sources as listed in Table 2. These estimates were mostly based on simulation modelling. While they show differential regional impacts, they do not capture climate variability within and between seasons. Due to this data limitation, the present study did not consider seasonality shift and the associated potential effect of lowering the quality of grain and livestock products.

Table 2: Climate change impacts on crop and pasture yields in Victorian regions

<table>
<thead>
<tr>
<th>Region</th>
<th>Grain crops</th>
<th>Sheep/Beef pasture</th>
<th>Dairy pasture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallee</td>
<td>-20% (GO)</td>
<td>-20% (Assumed)</td>
<td>(not applicable)</td>
</tr>
<tr>
<td>Wimmera</td>
<td>+10% (GO)</td>
<td>-6% (BC1)</td>
<td>(not applicable)</td>
</tr>
<tr>
<td>North-central</td>
<td>+10% (GO)</td>
<td>-6% (BC1)</td>
<td>(not applicable)</td>
</tr>
<tr>
<td>North East</td>
<td>+10% (GO)</td>
<td>-6% (BC1)</td>
<td>(not applicable)</td>
</tr>
<tr>
<td>South West</td>
<td>(not applicable)</td>
<td>+4% (BC2)</td>
<td>-1% (BC2)</td>
</tr>
<tr>
<td>Gippsland</td>
<td>(not applicable)</td>
<td>-5% (Assumed)</td>
<td>-3% (BC3)</td>
</tr>
</tbody>
</table>

(a) (GO): O’Leary et al. (2011)
(b) (BC1): Cullen, 2011, pers. Com., unpublished data
(c) (BC2): Cullen et al. (2008)
(d) (BC3): Cullen et al. (2009)

Specifically, yield of grain crops in the Mallee region was projected to decline while grain yield in other regions was projected to increase. Pasture yield was projected to decline in all regions except for sheep/beef pasture in South West Victoria.

Using these data, the integrated whole-farm models were solved for scenarios with and without the projected changes in crop and pasture yields. The ‘without changes’ scenario represents the base case reflecting current climate conditions and yields. The ‘with changes’ scenario reflects the incidence of climate change. The impact of climate change was then derived as the difference between those two scenarios. The impact of climate change adaptation was derived as described below.
4.2 Potential benefits of adaptation options

An objective of our whole-farm modelling is to build up the capability to, among other things, identify and evaluate adaptation options that can help mitigate the potential adverse impacts of climate change. This capability is essential for informing policies in relation to research and development and structural adjustment. For example, Scott et al. (2011) used APSIM and enterprise budgeting to assess different adaptation options in sorghum systems in NSW.

A number of scientists had suggested adaptation strategies for Victorian agriculture over different timeframes — namely: develop and adopt new crop varieties and alter management practices in the medium term; and shift some farming systems towards south in the longer term (Howden et al. 2007; Howden and Stokes, 2010; O’Leary et al. 2011; Tostovrsnik et al. 2010). The medium-term strategies focus on achieving ‘incremental’ changes to farming systems to bring about adaptation benefits. However, these benefits might not be sustainable if climate change becomes more extreme. Consequently, the long-term strategies could be necessary to achieve ‘transformational’ adaptations through land use and system changes (Howden et al. 2010).

While the above adaptation strategies aim to reduce losses in crop, pasture and livestock production, there are also strategies being investigated for identifying and capitalising on opportunities to actually gain from climate change. This type of research remains at an early stage, but has already generated innovative ideas such as adapting farming systems to changed seasonality through the introduction of summer crops into winter-grain cropping systems in northern Victoria (Dassanayake 2011).

For our study, the modelling was concerned with medium-term adaptation options — specifically, the introduction of new crop varieties. Other modelling capabilities, including the incorporation of transformational adaptation options, can be developed using the integrated modelling framework in the future.

We modelled the outcomes of adopting new varieties of grain crops that are tolerant to the changed climate. This adaptation is relevant only to Mallee where grain crop yields were projected to be lower by 20% under the assumed climate change scenario. Grain crop yields in the other regions were projected to increase under climate change, hence not requiring intervention. As such, the modelling of climate change adaptation was confined to the Mallee region.

Two adaptation scenarios were considered: namely, (Adaptation 1) new varieties of grain crops are developed to halve the projected yield loss under climate change (Table 2); and (Adaptation 2) new crop varieties are developed to prevent the loss totally. It was assumed that the introduction of new crop varieties does not require additional farm inputs.

4.3 Results and discussion

A main outcome of our research is the computationally efficient methodology for integrating EPRB whole-farm LP models into a flexible framework that can be applied at Victoria-wide spatial scale. The case study of climate change adaptation options confirmed a particular strength of the integrated modelling approach — that is, enabling the use of GIS layers to aggregate modelling results by different sectoral and geographical scales.

The impacts of climate change were found to vary between farm systems and between regions (Table 3). Modelling results suggest that climate change could lead to increased profitability of mixed farming systems in north east (by 14%) and north central Victoria (by 9%), grain farming systems in Wimmera (by 16%), and beef cattle and sheep farming systems in south west Victoria (both by 5%). For the other regional farming systems, however, climate change could reduce profitability. Potential decline in profitability ranges from 1% for dairy farming systems in the south west to 26% for mixed farming systems in Mallee.

Using the land area utilised by each regional farm type as the gross-up factor, we converted the farm-level results into regional aggregates (Figure 3). Without adaptation, the impact of climate change on dryland farming in Victoria was estimated to be a reduction in total farm profit by $80 million (or 2%) relative to the base case. As a point of comparison, the study by Gunasekara et al. (2007) suggested a climate change impact of 4% reduction in gross state product of Victoria. Our estimate is lower because it was derived with the inclusion of carbon fertilisation benefits whereas the fertilisation effect was ignored in the study by Gunasekara et al. (2007).
Table 3: Summary of modelling results for different farm types

<table>
<thead>
<tr>
<th>Region</th>
<th>Farm system</th>
<th>Farm gross margin ($/ha)</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base</td>
<td>CC</td>
<td>($/ha) (%)</td>
</tr>
<tr>
<td>North-central</td>
<td>Mixed</td>
<td>381.14 415.43</td>
<td>+34.29 9.0</td>
</tr>
<tr>
<td>North East</td>
<td>Mixed</td>
<td>271.63 309.58</td>
<td>+37.95 14.0</td>
</tr>
<tr>
<td>Mallee</td>
<td>Mixed</td>
<td>198.87 147.98</td>
<td>-50.89 -25.6</td>
</tr>
<tr>
<td>Wimmera</td>
<td>Grains</td>
<td>321.75 371.68</td>
<td>+49.93 15.5</td>
</tr>
<tr>
<td>Gippsland</td>
<td>Dairy cattle</td>
<td>1,223.45 1,180.61</td>
<td>-42.85 -3.5</td>
</tr>
<tr>
<td>South West</td>
<td>Dairy cattle</td>
<td>778.26 768.77</td>
<td>-9.49 -1.2</td>
</tr>
<tr>
<td>Gippsland</td>
<td>Beef cattle</td>
<td>369.54 349.35</td>
<td>-20.19 -5.5</td>
</tr>
<tr>
<td>South West</td>
<td>Beef cattle</td>
<td>148.56 155.87</td>
<td>+7.31 4.9</td>
</tr>
<tr>
<td>North East</td>
<td>Beef cattle</td>
<td>193.25 179.60</td>
<td>-13.65 -7.1</td>
</tr>
<tr>
<td>Wimmera</td>
<td>Sheep</td>
<td>146.32 135.48</td>
<td>-10.83 -7.4</td>
</tr>
<tr>
<td>South West</td>
<td>Sheep</td>
<td>189.72 198.68</td>
<td>+8.96 4.7</td>
</tr>
<tr>
<td>North East</td>
<td>Sheep</td>
<td>133.66 123.59</td>
<td>-10.07 -7.5</td>
</tr>
</tbody>
</table>

The impact of climate change was estimated to vary across regions, with the estimated impact ranging from a gain of $42 million (or 7% relative to the base case) for Wimmera to a reduction of $128 million (a decline by 26%) for Mallee (Table 4). Climate change was projected to increase grain crop yields in mid-north Victoria encompassing Wimmera and North East. Such projected yield increases underpin the estimated positive impact of climate change on Wimmera, but were offset by the projected pasture yield reductions in North East (Figure 3). For Mallee, grain crop and pasture yields were projected to decline under climate change, hence contributing to a significant negative regional impact.

A small but positive regional impact of climate change ($17 million or 2% relative to the base case) was estimated for the South West region. This result is consistent with the projection of higher grain and beef/sheep pasture yields under climate change, notwithstanding the projected marginal decline in dairy pasture yields.
Table 4: Summary of modelling results per region

<table>
<thead>
<tr>
<th>Region</th>
<th>Impact of CC</th>
<th>Value of Adaptation 1 ($m)</th>
<th>Value of Adaptation 2 ($m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallee</td>
<td>-128.3</td>
<td>63</td>
<td>126</td>
</tr>
<tr>
<td>Wimmera</td>
<td>+41.5</td>
<td>(not applicable)</td>
<td>(not applicable)</td>
</tr>
<tr>
<td>North-central</td>
<td>+40.1</td>
<td>(not applicable)</td>
<td>(not applicable)</td>
</tr>
<tr>
<td>North East</td>
<td>-19.2</td>
<td>(not applicable)</td>
<td>(not applicable)</td>
</tr>
<tr>
<td>South West</td>
<td>+16.6</td>
<td>(not applicable)</td>
<td>(not applicable)</td>
</tr>
<tr>
<td>Gippsland</td>
<td>-30.3</td>
<td>(not applicable)</td>
<td>(not applicable)</td>
</tr>
</tbody>
</table>

For the South West region, the modelling did not consider a widely projected change in land use from livestock to grain cropping under climate change. The study by Tostovrsnik et al. 2010 raised the likelihood of grain cropping activities spreading into the high-rainfall southern regions of Victoria under climate change. This projection was attributed to the potential reduction in the frequency of water logging and flooding due to the reduced rainfall, which would make the region more suitable for grain crops. For future research, this type of spatial redistribution of farm types should be considered.

A small negative regional impact of climate change (minus $30 million or negative 5% relative to the base case) was estimated for the Gippsland region. As this region is dominated by livestock farming activities, the result largely reflects the projection of reduced sheep/beef and dairy pasture yields (Table 2).

The economic benefit of introducing new crop varieties to Mallee was estimated to be $63 million for Adaptation 1 and $126 million for Adaptation 2 (Table 4).
5. Conclusions

This paper describes an integrated approach to connecting regional whole-farm models and GIS layers. The aim has been to revitalise a set of existing LP models representing key farming systems in Victoria, hence expanding the capability of the EPRB in using these models for policy analysis. These models have been proven useful through time, but they are not suited to the type of spatial analysis that is increasingly required today. Different regional sectors and communities will be affected in different ways and to different degrees by climate change, water availability, government policy and other market developments. Some regions will benefit and others will suffer. The knowledge of differential regional impacts would be useful to policy makers.

Here we have reported the first step in a process that should eventually lead to a complete integration within a true spatially explicit model. The spatial features of the current model are aggregated at the regional level. For each region we know the total area of each farm type, so we can calculate regional impacts by solving all 12 whole-farm models and aggregating the results according to regional composition of farm types. The results are then presented on maps. This level of spatial resolution is sufficient for many problems, but for others we may want to know the actual location of the farms so we can relate farm performance to land features such as soil type or some productivity index. The capability to do this is present in our Matlab model, which can relate any set of maps to any set of farm models. The main challenge, however, is the extension of the whole-farm models so they can be adjusted according to some land productivity measure that may vary in space.

Even without the extensions discussed above, the current model has the advantage that it is able to package and process large amounts information without requiring users to copy and paste data into spreadsheets. The illustration we present regarding a climate change scenario shows the potential of the model, but additional work will be required to exploit the richness of the results. For example, we could perform analysis of shadow prices for any number of scenarios by reading and processing a set of results files. The results of these scenarios could have been obtained over a period of days or months or in different computers simultaneously, but each scenario run is associated to a binary file containing a full set of results. To access these results and analyse them requires Matlab code to be written for specific problems. Eventually the model could be wrapped within a friendly user interface to undertake the more common analyses. In the meantime there are many important questions that can be explored with the integrated system in its current form.

Further applications of integrated whole-farm modelling, as we have developed for Victorian dryland farming systems, are possible in the following areas:

- Carbon pricing — Objective coefficients (or activity budgets) can be adjusted to represent scenarios with and without a carbon price for quantifying the impact on each region, agricultural industry and farming system.

- Emissions reduction — Cost to farmers of mitigating requirements can be estimated by including new constraints reflecting allowable limits on emissions for different farming systems.

- Carbon offset — Value of a carbon offset activity can be estimated by including offset options, their costs and returns in whole-farm models.

- Environmental management — Impact of preventing or reducing nutrient run-off from a farming system can be estimated by including new constraints on the related environmental outcomes in the LP models.

- Drought — Impact of drought on farming systems in different regions can be quantified by linking crop and pasture yields to growing-season rainfall.
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Appendix 1

Approaches to farm modelling

Mathematical modelling of farming systems has a long history and has spanned across different levels and aspects of farming — from the genome, cell, tissue or plant level, to the paddock, enterprise, whole-farm or regional levels. Of particular relevance to this study is the use of bio-economic modelling to integrate biophysical aspects and economic considerations in farm operations.

Klein and Narayan (1992) traced the developments and applications of farm-level models in the United States and Canada since the 1920s. They noted that early approaches involved using desk calculators to assess whole-farm budgets. In the 1950s, the practice of computerised linear programming was adopted. With rapid advances in computing power in the 1960s, basic single-period linear programming models were extended into multi-period models, and other more sophisticated simulation models also started appearing.

The 1970s saw a shift away from farm-level modelling to using aggregate sectoral models for macro analysis. However, interest revived in farm-level models in the 1980s due to the shortcomings of aggregate models, particularly their inability to provide insights into policy implications of spatial and other types of heterogeneity.

Farm-level modelling that was most useful for policy analysis was recognised as having the following essential features — whole-farm, multi-period, recursive and dynamic. In practice, there was a predominance of static bio-economic modelling. Out of the forty farm-level models reviewed by Klein and Narayan (1992), only one was based on recursive modelling. Other key challenges identified for designing farm-models were related to specifying a relevant decision environment for farmers and incorporating risk and uncertainty into their decision making.

The review by Janssen and van Ittersum (2007) focused on bio-economic farm models, their differences and variations in methodology and specification. A distinction was made between mechanistic and empirical models. Mechanistic models are built on established scientific understanding of farm processes and, hence, are suitable for extrapolating and predicting system behaviour in response to innovations and policy changes. Empirical models are constructed using a data mining process to characterise particular aspects of the farming system. With this approach, changes in system behaviour are predicted based on extrapolation of estimated data relationships, which can be deficient in capturing the impact of any new technology or policy and market constraint on system behaviour.

A number of dynamic modelling approaches were discussed in the context of informing farmer decision making including recursive, inter-temporal, dynamic recursive and stochastic programming. These approaches were noted to provide only partial solutions to addressing risk and uncertainty in resource allocation and investment. Their major limitations were related to large data requirements and long solution time.

The importance of model transferability was stressed. Ideally, farm models should have the ability to replicate assessments for a vast range of spatial conditions and farming practices. This requires the development of a generic and modular structure as opposed to a location- and farm type-specific structure.

In summary, both reviews identified whole-farm modelling to be a preferred approach for policy analysis. While whole-farm models can be developed with different degrees of sophistication, they need to be ‘fit-for-purpose’ in practice depending on the type of problem on hand. For our study, it was considered practically adequate to use a relatively simple approach comparing ‘before’ and ‘after’ change to analyse climate change and related adaptation options.

Optimisation and simulation

Farm-level models can be based on an optimisation or a simulation approach.

Optimisation is useful approach for detailing whole-farm operations and tracking the performance and interaction of farming system components. It is commonly based on the use of linear or non-linear programming techniques. Given a specific objective of maximising profits or minimising costs, this type of model provides guidance on the optimal mix of farm activities within particular resource and operational constraints. Typically set in a comparative static framework, optimisation models can indicate how system behaviour would respond to changes in the farming system. Such exogenous system changes could relate to alteration in crop varieties, animal breeds, farm inputs, other technologies, management practices, prices and product qualities, as well as climate, market and policy influences.

Farmers adjust the mix of activities and inputs in order to optimise economic outcomes of farming under the changed situation. Therefore, optimisation models are particularly useful for ex ante analysis of the potential impacts of technology, market, climate and policy on farm practices, and for identifying necessary adjustments to accommodate such changes at minimal cost.
to farmers. Examples of using the whole-farm optimisation approach to assess research and development (R&D) outcomes can be found in the studies by DNRE (2000), Wimalasuriya et al. (2001) and Wimalasuriya et al. (2002).

Simulation is a powerful experimental approach for assessing detailed production processes at the paddock level. It supports model structures that reflect short time-steps (such as hourly, daily or weekly) and iteration of these steps over an extended time horizon (such as a number of seasons). This type of model can be calibrated to mimic historical enterprise performance (subject to availability of accurate input data) and replicate performance variability between time steps and across seasons. With these features, simulation models are particularly useful for agronomic experiments and for supporting farmer decision making.

Anderson (1974) reviewed the methodologies and applications of simulation modelling in agricultural economics. It was noted that simulation models generally lack the ability to reflect potential states of a system subject to changes that are not captured in their structures and data bases. For example, a simulation model may not allow for potential changes in crop mix necessary to accommodate some new technology in a profitable manner. The reason for this deficiency is twofold. First, simulation models are typically developed for a single crop, paddock or enterprise. Secondly — even for those with a whole-farm representation — they do not incorporate a mechanism to determine optimal adjustments to system changes.

Partial system analysis

The focus of this study is on whole-farm optimisation. Whole-farm modelling regards the entirety of all activities in a farm as a system (Barlow et al. 1980). Speedding (1979) provided a generic definition of system — that is, ‘a group of interacting components, operating together for a common purpose, capable of reacting as a whole, to external stimuli’. According to CGIAR (1978), a whole-farm system is ‘a complicated interwoven mesh of soils, plants, animals, implements, workers, other inputs and environmental influences with the strands held and manipulated by a person called the farmer’.

Typically, whole-farm optimisation models are used to examine system changes in isolation of price adjustments that may occur in both input and output markets. As such, they primarily support partial analysis of farm supply. The optimisation approach takes into account whole-farm adjustments (e.g. in respect of crop mix, feed mix or stocking rate) induced by technical change or improvement to some aspect of the farm system. In other words, exogenous technical change or farm practice improvement is augmented with adjustments in the farm system to enable the best economic outcomes at the farm level.

Partial analysis of farm adjustments can support market-wide or economy-wide impact analysis. For instance, a market analysis can capture the optimised farm-level outcome (in terms of profit increase or cost reduction after on-farm adjustment) as a vertical shift of the supply curve (called k2 factor; see Wimalasuriya et al. 2002).

By providing a better indication of the economic value in a particular technical change or system improvement, the optimisation approach improves over other approaches that are essentially based on extrapolation of estimated data relationships. For example, a new crop variety may bring yield increases that induce a shift in crop mix or crop rotation, generating economic value not only from yield increases but also from a shift in production towards crops with higher returns.

Whole-farm modelling in Australia

Both the optimisation and simulation approaches have been extensively used in Australia for research into farming systems. Examples of simulation model include APSIM (Agricultural Production Systems Simulator), GrassGro, GRASP and AussieGRASS. Other models such as APMAA (Aggregative Programming Model of Australian Agriculture), MIDAS (Model of an Integrated Dryland Agricultural System), PRISM (Profitable Resource Integration, Southern MIDAS), EMAR (Economic Model of Agronomic Rotations) and CAB (Complex Activity Budget) follow the optimisation approach.

Whole-farm modelling based on linear programming techniques was pioneered by researchers at the University of New England who developed the APMAA between 1972 and 1976. This model was used for numerous policy studies (Parton 1979).

Modelling crop rotations and paddock history impacts on weed, disease, nitrogen and moisture status of crops was first successfully conducted in Western Australia (WA) in the early 1980s. This research led to the development of MIDAS (Kingwell and Pannell 1987) and its regional versions — a product of collaboration between economists and scientists in WA Department of Agriculture and the University of Western Australia. A key technical feature of MIDAS is the use of linear programming techniques to optimise inter-temporal crop rotation, similar to the method used by Hildreth and Reiter (1951).

In early 1990s, the then New South Wales Department of Agriculture developed linear programming models of irrigated agricultural activities in the southern valleys of the state (Jones 1991). These models were not pertinent to farm-level analysis as they represented an aggregation of farm activities in individual irrigation regions. (These NSW models inspired the then
Department of Agriculture in Victoria to develop their own multi-regional Water Policy Model (WPM); see Eigenraam et al. 2003).

Drawing on MIDAS, the Departments of Agriculture in Victoria and New South Wales each developed a prototype of PRISM in 1996. The Victorian Department of Agriculture continued this research and created two Victorian regional versions of PRISM (Wimalasuriya 1998).

In 1999, the Victorian Department of Agriculture adopted a different approach from MIDAS and PRISM to develop EMAR (Wimalasuriya and Eigenraam 2000). The design of EMAR enables choosing optimal crop or crop-pasture rotation from all theoretically possible rotations generated from a combination of crops or pasture options on a pre-defined list. This approach is similar to the ROTAT model developed in Netherlands by Dogliotti et al. (2003). In 2001, the Department developed yet another range of models, called CAB, for dairy, sheep and beef farming systems (Wimalasuriya et al. 2002).

The cumulative research efforts by the Victorian Department of Primary Industries (DPI) and its predecessors over past two decades or so have delivered a comprehensive list of regional whole-farm models for the state. These regional models have been regularly updated and extensively used for evaluating research and development projects.
Appendix 2

An Inventory of Farm System Models Maintained by the Economics and Policy Research Branch (EPRB)

CONTENTS

INTRODUCTION

PRISM–NC (Profitable Resource Integration, Southern MIDAS – North-central)
PRISM–NE (Profitable Resource Integration, Southern MIDAS – North East)
EMAR–Mallee (Economic Model of Agronomic Rotations – Mallee)
EMAR–Wimmera (Economic Model of Agronomic Rotations – Wimmera)
Beef-Sheep CAB (Complex Activity Budget)
Dairy CAB (Complex Activity Budget)

INTRODUCTION

Farming system models are annual models that represent the farming system of a particular geographical region. The purpose of these models is to provide guidance on the optimal mix of farm activities. These models are used to evaluate the impact of changes due to research, development and extension (RD&E), and policy options.

All of the farming system models maximise total farm gross margin as their objective function, subject to a number of endogenous constraints. The main exogenous constraint is land area of the farm system.

Data for the models come from various sources. Prices of farm inputs and outputs have been sourced from ABARE (Australian Bureau of Agricultural and Resource Economics) and DPI (Department of Primary Industries) publications, and are updated regularly. Yield of crops, pasture and livestock products, and rates of input use have been suggested by research and extension staff in the regions represented by the models. Yields in the models are fixed as averages observed among the top farmers in a region and the rates of inputs are also fixed.

Broadacre crop-based models represent crop or crop–pasture rotations and the yield of the same crop may vary depending on the paddock history of the two previous years. These crop yields have been developed in consultation with a group of research and extension agronomists from each region.

All these models are in Excel spreadsheets and the Linear Programming matrices are optimised using the add-in software “What’s Best”.
PRISM–NC (Profitable Resource Integration, Southern MIDAS – North-central)

(MIDAS = Model of an Integrated Dryland Agricultural System)

Farming system modelled

Grain–sheep mixed farming system in North Central Victoria, where winter grain crops and pasture are rotated. The pasture is a self-regenerating, annual pasture (mainly sub clover-based).

Crops are rotated to minimise disease carry-over to the following crops, soil structure decline and nitrogen (and other nutrients) depletion in the soil. Ability to control weeds more effectively is another benefit of rotating crops.

Major assumptions

The basic assumptions in modelling crop rotations is that each phase of a rotation is occurring on a farm across paddocks in equal proportions in the current year, and continuously rotated within the farm from year to year. This assumption is similar to that of the MIDAS models in WA. In real world situation, this is a common practice across most of the farming area in a region.

In calculating expected crop yields depending on two-year paddock histories, the pasture phase was assumed to be a properly managed, legume dominant, under-sown sub clover pasture with grasses removed prior to cropping.

Region/s represented

North-central region of Victoria, comprising approximately one and a half million hectares of land, situated between the northern foothills of the Great Dividing Range and the irrigation districts of Northern Victoria.

Average rainfall varies from 500 mm in the south of the area to 350 mm in the north. Duplex soils are predominant in the region, varying from red duplex on the plains in the north to yellow duplex and gradational soils in the south and along the foothills. Dryland cropping and sheep grazing for wool and meat are the major broadacre farming enterprises in the region.

Types of activities and potential shocks for modelling

The main set of activities consists of crop–pasture rotations. After consultation with local agronomists, 114 common rotations under 6 different categories have been included. These categories include combinations of varying lengths of pasture (P) and cropping (Cr) phases. They are 2P 3Cr (2 years of pasture followed by 3 years of cropping), 2P 4Cr, 3P 3Cr, 3P 4Cr, 4P 4Cr and 4P 5Cr. The crops refer to wheat, barley, oats, canola and lupins. Other model variables include the stock numbers that could be carried on the farm system, livestock feeding options and sale of crop and livestock products.

Model shocks may include yield and price of farm outputs, and rate and price of farm inputs such as fertiliser and chemicals. Yields and rate of inputs are not linked and have to be shocked manually. The model maximises total farm gross margin to determine the optimal crop-pasture rotation, stocking rate and feeding options. The optimal rotation is based on price and yield of crops in a rotation.
PRISM–NE (Profitable Resource Integration, Southern MIDAS – North East)

Farming system modelled

Grain–sheep mixed farming system in North East Victoria, where winter grain crops and pasture are rotated. The pasture may be either self-regenerating, annual pasture (mainly sub clover-based) or lucerne pasture.

Crops are rotated to minimise disease carry-over to the following crops, soil structure decline and nitrogen (and other nutrients) depletion in the soil. Ability to control weeds more effectively is another benefit of rotating crops.

Major assumptions

The basic assumptions in modelling crop rotations is that each phase of a rotation is occurring on a farm across paddocks in equal proportions in the current year, and continuously rotated within the farm from year to year. This assumption is similar to that of the MIDAS models in WA. In real world situation, this is a common practice across most of the farming area in a region.

In calculating expected crop yields depending on two-year paddock histories, the pasture phase was assumed to be a properly managed, legume dominant, under-sown sub clover or lucerne pasture with grasses removed prior to cropping.

Region/s represented

The North East region of Victoria comprises approximately two million hectares of diverse agricultural land. Land types vary from high rainfall grazing country to the cropping-livestock country of the Riverina plain.

Duplex soils are predominant in the region, varying from red duplex (with sodic subsoils) on the plains in the north to yellow duplex and gradational soils in the south and along the foothills. Dryland cropping, sheep for wool and meat production and cattle are the major broadacre farming enterprises in the region.

Types of activities and potential shocks for modelling

The main set of activities consists of crop–pasture rotations. After consultation with local agronomists, 164 common rotations under 6 different categories have been included. These categories may include any combination of either annual or lucerne pasture of 1 to 5 year length with a 3 to 5 year crop sequence. The crops refer to wheat, barley, triticale, canola and lupins. Other model variables include the stock numbers that could be carried on the farm system, livestock feeding options and sale of crop and livestock products.

Model shocks may include yield and price of farm outputs, and rate and price of farm inputs such as fertiliser and chemicals. Yields and rate of inputs are not linked and have to be shocked manually. The model maximises total farm gross margin to determine the optimal crop-pasture rotation, stocking rate and feeding options. The optimal rotation is based on price and yield of crops in a rotation.
EMAR–Mallee (Economic Model of Agronomic Rotations – Mallee)

Farming system modelled

Grain-sheep mixed farming system in the Victorian Mallee, where winter grain crops, pasture and long fallow phases are rotated. The pasture is a self-regenerating, annual medic pasture.

Crops are rotated to minimise disease carry-over to the following crops, soil structure decline and nitrogen (and other nutrients) depletion in the soil. Ability to control weeds more effectively and to conserve soil moisture is another benefit of rotating crops.

Major assumptions

The basic assumptions in modelling crop rotations is that each phase of a rotation is occurring on a farm across paddocks in equal proportions in the current year, and continuously rotated within the farm from year to year. This assumption is similar to that of the MIDAS models in WA. In real world situation, this is a common practice across most of the farming area in a region.

In calculating expected crop yields depending on two-year paddock histories, the pasture phase was assumed to be a properly managed, legume dominant, under-sown medic pasture with grasses removed prior to cropping.

Region/s represented

The Victorian Mallee region is approximately 4.3 million ha in extent with 2.6 million ha of agricultural land. It is contiguous with the Mallee areas of South Australia and New South Wales. The Victorian Mallee region is semi-arid to arid with annual rainfalls ranging from 250 to 375 mm.

Broadacre cropping is the most important land use in the dryland Mallee with cereal crops, pasture and fallow accounting for most of these calcareous sandy loam soils. On average, only half of the farms are cropped in any given year and the rest are under annual pasture or fallow.

Types of activities and potential shocks for modelling

EMAR adopts an unrestricted approach, where even new rotations that are not commonly practiced by farmers, can be evaluated. The model develops the optimal crop rotation, from all possible crops grown after all possible two-year paddock histories. Crop/pasture options considered are Wheat (Wh), Barley (Bl), Field Peas (Fp), Canola (Ca), Fallow (F) and Pasture (P). These six options after each of the theoretically possible two-year paddock histories (36) result in 216 land-use activities. This is only for one single phase of the rotation. This set of 216 land-use activities is duplicated to represent up to 6 phases of a rotation.

“Transfer Rows” are used to transfer two-year paddock histories between these phases. These will transfer the 2nd crop of the history and the crop selected in the current phase as the two-year history for the following phase. For example, if the selected option in the 1st phase is Wh after P-F, a History of F-Wh will be transferred to the 2nd phase. This would restrict the choice of crop in the 2nd phase to be only after F-Wh history. These history transfers will occur from phases 1 to 2, 2 to 3, 3 to 4, 4 to 5, 5 to 6 and from 6 back to 1. This would result in the optimal solution to be a continuous cycle of a crop–pasture–fallow rotation. Other model variables include the stock numbers that could be carried on the farm system, and livestock feeding options.

Model shocks may include yield and price of farm outputs, and rate and price of farm inputs such as fertiliser and chemicals. Yields and rate of inputs are not linked and have to be shocked manually. The model maximises total farm gross margin to determine the optimal crop-pasture rotation, stocking rate and feeding options. The optimal rotation is based on price and yield of crops in a rotation.
EMAR–Wimmera (Economic Model of Agronomic Rotations – Wimmera)

Farming system modelled

Continuous cropping system in the Victorian Wimmera, where winter cereal crops are rotated with oilseed crops and high-value pulse crops.

Crops are rotated to minimise disease carry-over to the following crops, soil structure decline and nitrogen (and other nutrients) depletion in the soil. Ability to control weeds more effectively and to conserve soil moisture is another benefit of rotating crops. If weed control becomes problematic as the crop rotation cycle is repeated several times, those paddocks would be rested for a year or two under a green manure crop, a legume pasture or a fallow.

Major assumptions

The basic assumptions in modelling crop rotations is that each phase of a rotation is occurring on a farm across paddocks in equal proportions in the current year, and continuously rotated within the farm from year to year. This assumption is similar to that of the MIDAS models in WA. In real world situation, this is a common practice across most of the farming area in a region.

Region/s represented

The Wimmera region comprises approximately two million ha farmland, situated in central western Victoria. The model is presently calibrated to Murtoa, receiving an average annual rainfall of 400 mm.

Wimmera self-mulching grey clay is the major soil type, comprising approximately 40% of the land area. Dryland cropping and sheep for wool production are the major enterprises in the region.

Types of activities and potential shocks for modelling

EMAR adopts an unrestricted approach, where even new rotations that are not commonly practiced by farmers, can be evaluated. The model develops the optimal crop rotation, from all possible crops grown after all possible two-year paddock histories. Crop options considered are Wheat (Wh), Barley (Bl), Field Peas (Fp), Lentils (Lt) and Canola (Ca). These five options after each of the theoretically possible two-year paddock histories (25) result in 125 land-use activities. This is only for one single phase of the rotation. This set of 125 land-use activities is duplicated to represent up to 6 phases of a rotation.

“Transfer Rows” are used to transfer two-year paddock histories between these phases. These will transfer the 2nd crop of the history and the crop selected in the current phase as the two-year history for the following phase. For example, if the selected option in the 1st phase is Wh after Ca-Fp, a history of Fp-Wh will be transferred to the 2nd phase. This would restrict the choice of crop in the 2nd phase to be only after Fp-Wh history. These history transfers will occur from phases 1 to 2, 2 to 3, 3 to 4, 4 to 5, 5 to 6 and from 6 back to 1. This would result in the optimal solution to be a continuous cycle of a crop rotation.

Model shocks may include yield and price of farm outputs, and rate and price of farm inputs such as fertiliser and chemicals. Yields and rate of inputs are not linked and have to be shocked manually. The model maximises total farm gross margin to determine the optimal crop rotation. The optimal rotation is based on price and yield of crops in a rotation.
**Beef-Sheep CAB (Complex Activity Budget)**

**Farming system modelled**

Pasture-based sheep and beef cattle farming systems.

When running the model, it is possible to choose between regions (South West, Gippsland, North East), between farm types (lamb, wool, beef), between enterprises (Merino wool, second-cross prime lamb, first-cross prime lamb, Merino wethers, vealer, store weaner, store steer, yearling steer, bullock, backgrounder) and between pasture production curves at different locations, for each model run.

**Major assumptions**

Although the Beef-Sheep CAB model is an annual model, it is based on a monthly feed budget. Pasture production curve and pasture quality data used in the model are outputs from the CSIRO-developed simulation model, GrassGro. Monthly feed requirements of the livestock are calculated based on fixed production targets and herd/flock structure.

**Region/s represented**

South West, Gippsland, North East and Southern Wimmera regions of Victoria.

**Types of activities and potential shocks for modelling**

The main set of activities consists of the stock numbers that could be carried on the farm system, livestock feeding options and sale of livestock products.

Model shocks may include yield and price of farm outputs, yield and quality of pasture, nutrient requirement of animals, and rate and price of farm inputs such as feed grain, hay, fertiliser and chemicals. Yields and rate of inputs are not linked and have to be shocked manually. The model maximises total farm gross margin to determine the optimal stocking rate and feeding options.
Dairy CAB (Complex Activity Budget)

Farming system modelled

Pasture-based dairy farming systems.

When running the model, it is possible to choose between irrigated and dryland dairying, between regions (South West, Gippsland, Goulburn Valley), and between pasture production curves at different locations, for each model run.

Major assumptions

Although the Dairy CAB model is an annual model, it is based on a monthly feed budget. Pasture production curve and pasture quality data used in the model are outputs from the CSIRO-developed simulation model, GrassGro. Monthly feed requirements of the livestock are calculated based on fixed production targets and herd structure.

Region/s represented

South West, Gippsland and Goulburn Valley regions of Victoria.

Types of activities and potential shocks for modelling

The main set of activities consists of the stock numbers that could be carried on the farm system, livestock feeding options and sale of livestock products.

Model shocks may include yield and price of farm outputs, yield and quality of pasture, nutrient requirement of animals, and rate and price of farm inputs such as feed grain, hay, fertiliser and chemicals. Yields and rate of inputs are not linked and have to be shocked manually. The model maximises total farm gross margin to determine the optimal stocking rate and feeding options.