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Dynamic general equilibrium analysis of improved weed management in Australia's winter cropping systems*

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A recent analysis indicated that the direct financial cost of weeds to Australia's winter grain sector was approximately $A1.2bn in 1998–1999. Costs of this magnitude represent a large recurring productivity loss in an agricultural sector that is sufficient to impact significantly on regional economies. Using a multi-regional dynamic computable general equilibrium model, we simulate the general equilibrium effects of a hypothetical successful campaign to reduce the economic costs of weeds. We assume that an additional $50m of R&D spread over five years is targeted at reducing the additional costs and reduced yields arising from weeds in various broadacre crops. Following this R&D effort, one-tenth of the losses arising from weeds is temporarily eliminated, with a diminishing benefit in succeeding years. At the national level, there is a welfare increase of $700m in discounted net present value terms. The regions with relatively high concentrations of winter crops experience small temporary macroeconomic gains.

Key words: CGE modelling, dynamics, weed management.

1. Introduction

Weeds impose substantial annual costs on Australia's winter grain producers by reducing yields, by contaminating grain and by the costs incurred in weed control practices. A national survey conducted during 1998–1999 found that weeds were the main management problem facing more than 90 per cent of Australia's winter cereal and oilseed producers (Jones *et al.* 2000). Producers were asked to rank weeds relative to other land management problems, to nominate the most difficult weeds to control, to estimate the areas and densities of weeds remaining after spraying, to indicate their weed management practices and to estimate yields under existing weed populations compared to weed-free cropping systems. Weeds outranked crop diseases, insect pests and soil deficiency problems by more than 20 per cent in terms of adverse impact on farming enterprises, and weed costs across all regions and crops ranged between $28.40 and $358.80 per hectare. Most winter grain producers stated that weed problems had

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either worsened or remained unchanged compared to five years earlier. The survey data revealed that winter crop weed problems were increasing nationally and that major weeds were persisting despite efforts at control.

Economic evaluations of crop weed costs have usually been undertaken at either the production systems level (e.g., Jones and Medd 2000) or the grains industry level (e.g., Medd and Pandey 1990). A rare example that addresses both levels is Jones *et al.* (2004) who used the results of the 1998–1999 survey to estimate the annual economic cost of weeds in winter crop production. Weed costs were estimated over the three main regions that comprise the bulk of Australia's winter cropping areas: the northern region that covers central and south-eastern Queensland and northern New South Wales to the west of the Great Dividing Range; the southern region that includes southern New South Wales and all of Victoria and South Australia; and the western region that represents the grain-growing regions of Western Australia. The direct financial cost included \$571m for herbicide purchases; \$380m for the adverse effects of residual weeds on grain yields; \$206m for the cultivation requirements for weed control; and \$25m for grain contamination (totalling \$1.182bn). This cost was split three ways: \$526.5m in the southern region, \$452.8m in the western region and \$203.1m in the northern region. Nearly 60 per cent of this cost was incurred in wheat growing. The most important weeds across all regions were annual ryegrass, wild oats and wild radish that together accounted for nearly 90 per cent of the total value of winter crop yield losses.

Over seven of the main winter crops, the annual value of the economic surplus changes to grain producers and consumers from weed-affected winter grain production was estimated to be \$1.279bn (Jones *et al.* 2004). That cost was equivalent to 18.5 per cent of the value of Australian grain and oilseed production for that year (ABARE 2005). It is interesting to compare these estimates with those recently compiled by Sinden *et al.* (2005). Using a partial equilibrium approach, they estimated that the mean cost of weeds across all crops was \$1.518bn per annum, and across the livestock industries was \$2.409bn. Thus winter crops represent approximately one-third of the aggregate cost of weeds in Australian agriculture.

The study of the economic impacts of weeds on broadacre crops reported here differs from earlier studies in three important ways. First, we use a multi-regional general equilibrium model, in which additional production costs and yield losses arising from weeds impact on the labour and capital markets at the regional level. Second, we use a dynamic approach, where we compare a policy simulation year–by year with a base forecast of the economy at the regional level. Third, our approach is to estimate the benefits of a major initiative to partially reduce weed costs, rather than the total costs of weeds relative to a hypothetical world without weeds.

Computable general equilibrium (CGE) models of the ORANI and MONASH family (Dixon *et al.* 2002) have been used to simulate the impacts of many different economic and policy scenarios. Some examples have been in evaluating mineral discoveries, new technology introduction, infrastructure projects, labour market reforms, and changes in policy instruments such as tax and tariff rates, public spending, interest rates and environmental regulations. ORANI-style models have been adapted to many countries other than Australia.

2. Methods

The model used in this study is known as TERM (The Enormous Regional Model, Horridge *et al.* 2005). The master database of TERM consists of over 150 sectors. These mostly correspond to the 107 sector input–output table published by the Australian Bureau of Statistics (ABS), plus additional sectors covering mainly agricultural industries. The database also includes 58 regions that largely correspond to the ABS statistical divisions. In running the model, we aggregate the database to examine sectors and regions of interest, and we solve it using the GEMPACK software (Harrison and Pearson 1996). Unlike earlier versions of the disaggregated MONASH model such as MMRF and MMRF-Green (Adams *et al.* 2003; Wittwer *et al.* 2005), TERM represents sub-state economies in a 'bottom-up' manner, where each region has its own behavioural equations, input–output database and inter-regional trade matrices. In the MMRF models, sub-state regions are represented in a 'top-down' manner, relying on state-wide behavioural equations and input–output data.

For the weed application reported here, the database includes 25 sectors (including wheat, barley, oats, canola and other broadacre crops) and 11 regions. New South Wales is divided into three sectors: northern cropping, southern cropping and the rest of New South Wales. Victoria, Queensland and South Australia are each divided into two: cropping and non-cropping. A single region represents Western Australia, and a single composite region covers Tasmania and the two territories.

The model is typical of CGE models in that each industry minimises its costs of producing a given level of output by optimising inputs of labour, capital and materials. The levels of output are chosen to satisfy demands by users, which include other domestic industries, capital creators, households, governments and exports. Demands reflect prices and incomes. TERM differs from national models including ORANI, in that each commodity is produced by an industry in each region instead of being produced by a single national industry.

Also, unlike a typical national CGE model with a single government and household, TERM has a household in each region, a national government and six state governments. The six state governments map to the 11 regions: for example, the New South Wales state government maps to the three New South Wales regions. Each sector produces a single commodity and investment activity produces sector-specific units of capital. Changes in rates of return on capital affect industry investment levels, and this results in year-by-year adjustments to capital stocks. The baseline national labour supply is determined by demographic factors. Labour is mobile between regions, as is capital via investment responses at the regional industry level, so that each region's productive resource stock is a reflection of regional labour markets and relative rates of return. Labour is imperfectly mobile, in that we allow regional differences to arise in real wages both in the short and long term in a policy scenario. A sticky-wages assumption operates at the regional level, so that initially, labour market adjustments arise through changes in regional employment more so than through changes in regional real wages. After a number of years, regional real wages may differ from national wages, so that not all adjustment in the long run is borne by inter-regional movements of labour (this theory is detailed in the Appendix for interested readers).

In running the model dynamically, we first construct a baseline forecast where we impose macro forecasts and trade variables from agencies including Access Economics (2005) and ABARE (2005), together with trend forecasts of demographic, technological and consumer-preference variables. The model produces detailed forecasts for industries and regions. In running a policy scenario, the model produces deviations from forecast paths in response to shocks relevant to the hypothesis being explored.

In this study, we assume that there are temporary technological changes in winter cropping in addition to the technological changes imposed in the baseline forecast. Specifically, we start a 5-year weed control campaign with funding above and beyond base-level R&D investments. This campaign costs an additional $10m per annum ($50m in total) commencing in 2002, and is ascribed as an increase in the use of agricultural services by the relevant cropping sectors. In practice, it is difficult to estimate the direct marginal benefits of a particular R&D effort. To illustrate our scenario, we assume that the benefits, commencing in 2007, are a 10 per cent reduction in weeds-related intermediate-input costs as cultivation and spraying costs fall. While this investment provides a large welfare benefit, there are circumstances under which the welfare benefit of a successful campaign could be negligible, as discussed later. We represent the benefits as reductions in fuel, machinery and chemical requirements by the cropping sectors. Increased yields arising from weed reductions are treated as primary factor productivity improvements, and for the export-oriented sectors (wheat and barley), reduced price penalties (the smallest of the weed effects in the raw data) are ascribed as outward shifts of their export demand curves. Each cost reduction or yield increase is ascribed as a proportional increase based on the 1998–1999 survey results (Jones *et al.* 2000). However, the database of TERM is updated each year to reflect various micro and macro forecasts. The imposed primary and intermediate input-cost reductions for each crop and region for the year 2007 are shown in Table 1. Thereafter, we assume that the direct benefits of the R&D campaign diminish, with approximately 10 per cent of the cost savings, yield benefits and output price increases being eroded in each successive year from 2008 onwards, with return-to-base forecast levels by 2017. Our assumption of diminishing benefits is based on the tendency for weeds to develop resistance over time, and also the possibility that some of the R&D benefits of this program would eventually be realised through other sources.

3. Results

3.1 National results

The impact of improved weed control on the national outputs of the directly affected winter crops is shown in Figure 1. In the case of wheat, the largest of the crop sectors, increased yields and reduced spraying and cultivation costs result in an increase in output of more than 2 per cent relative to the base forecast in the year 2007. Thereafter, the direct benefits of improved weed management gradually diminish and wheat output returns to near-the-base forecast by 2017. Differences in percentage output effects reflect differences in total demand elasticities plus differences in direct cost reductions shown in Table 1. The total demand elasticity for each crop increases with the share of

Table 1 Productivity shocks ascribed in policy simulation for 2007

	Total factor productivity shocks (%)[†]				
	Wheat	Barley	Oats	Canola	Other broadacre
New South Wales northern cropping	−1.4	−0.5	−1.2	−2.3	−0.2
New South Wales southern cropping	−1.3	−0.8	−0.7	−1.9	−0.2
Victorian cropping	−1.3	−0.8	−0.7	−1.9	−0.2
Queensland cropping	−1.4	−0.5	−1.2	−2.3	−0.2
South Australian cropping	−1.3	−0.8	−0.7	−1.9	−0.2
Western Australian cropping	−2.0	−1.0	−1.6	−1.6	−0.9
	Intermediate input shocks (%)[‡]				
New South Wales northern cropping	−0.5	−0.4	−0.6	−0.3	−0.1
New South Wales southern cropping	−0.5	−0.4	−0.5	−0.4	−0.2
Victorian cropping	−0.5	−0.4	−0.5	−0.4	−0.2
Queensland cropping	−0.5	−0.4	−0.6	−0.3	−0.1
South Australian cropping	−0.5	−0.4	−0.5	−0.4	−0.2
Western Australian cropping	−0.6	−0.5	−0.5	−0.4	−0.3

Source: Authors' estimates derived from Jones *et al.* (2000). [†]A negative sign indicates a reduction in input requirement and therefore a productivity gain; [‡]Change in total intermediate input costs as per cent of total costs of production. Shocks were given to other manufactures to reflect reduced spraying costs, and to motor vehicles and other transport equipment and fuel inputs to reflect reduced cultivation costs.

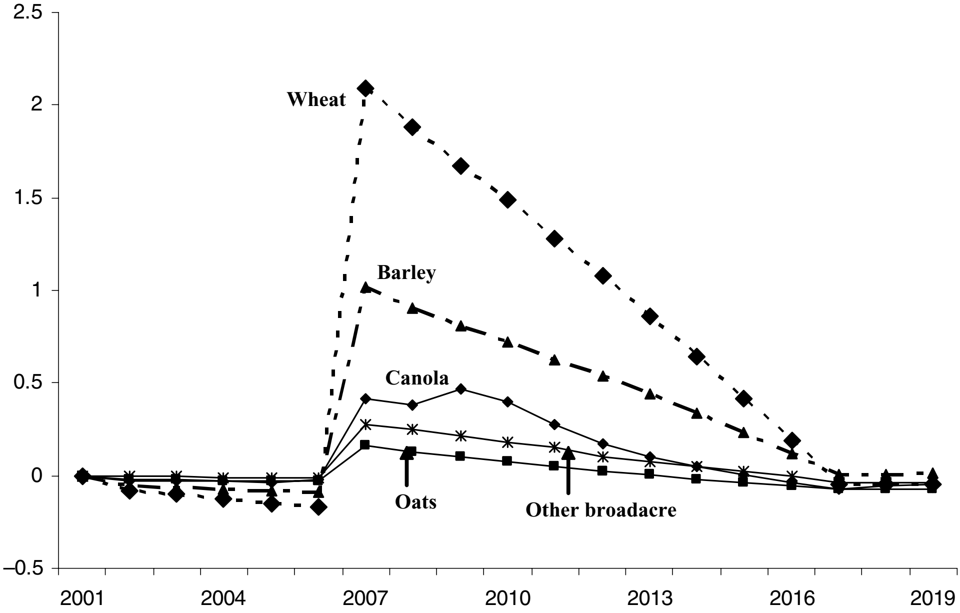

Figure 1 National output of sectors directly affected by weeds program (% change relative to forecast).

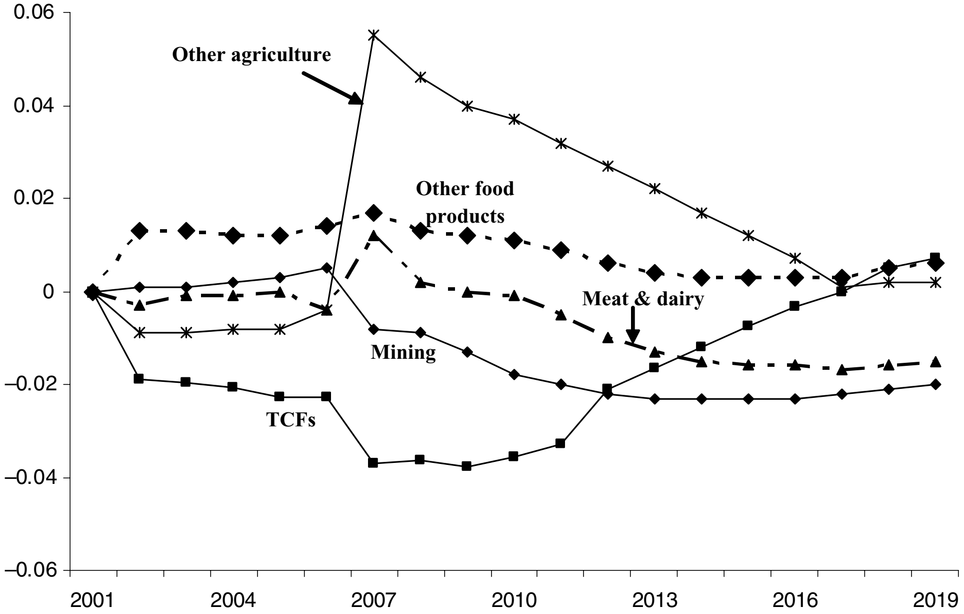

Figure 2 National output of other sectors (% change relative to forecast).

exports in total sales, as exports have the highest price elasticities of any sales points. Wheat is the most export-oriented of the crops, and therefore has the highest total demand elasticity, so that for a given percentage of cost reduction, there is a larger percentage of output increase than for the other crops.

CGE analysis also allows us to examine industries that are indirectly affected by the policy shocks (Figure 2). Initially, costs for 'other agriculture' increase, as the price of a significant input, services to agriculture, rises because of the weeds R&D effort. From 2007, lower input costs arising from improved weed management provide gains: the livestock component of 'other agriculture' relies to some extent on grain inputs and so benefits from the increased grain production brought about by improved management of weeds in winter crops. Similarly, the downstream processing sectors 'other food products' and 'meat and dairy' benefit from controlling winter crop weeds. There are also losers that we can explain after examining the macroeconomic impacts.

The national macroeconomic results of the weed control scenario are shown in Figures 3–5. Real gross domestic product (GDP) increases above the base forecast in 2007 as the intermediate input savings and crop yield increases take effect (Figure 3). This is accompanied by an increase in national employment, which peaks in 2008 at 0.012 per cent or 1200 jobs above the base level. Since capital formation relies on previous investment (responding to rises in rates of return), there is a lag before capital stocks increase. Capital stocks eventually reach 0.008 per cent above the base forecast in 2014, before gradually moving back to base forecast levels. Real wages rise steadily (peaking in 2013 at 0.02 per cent above forecast), thereby pushing employment back towards the base forecast. Prior to 2007, the textiles, clothing and footwear (TCF) sector loses slightly relative to the base forecast as the price of services to agriculture inputs

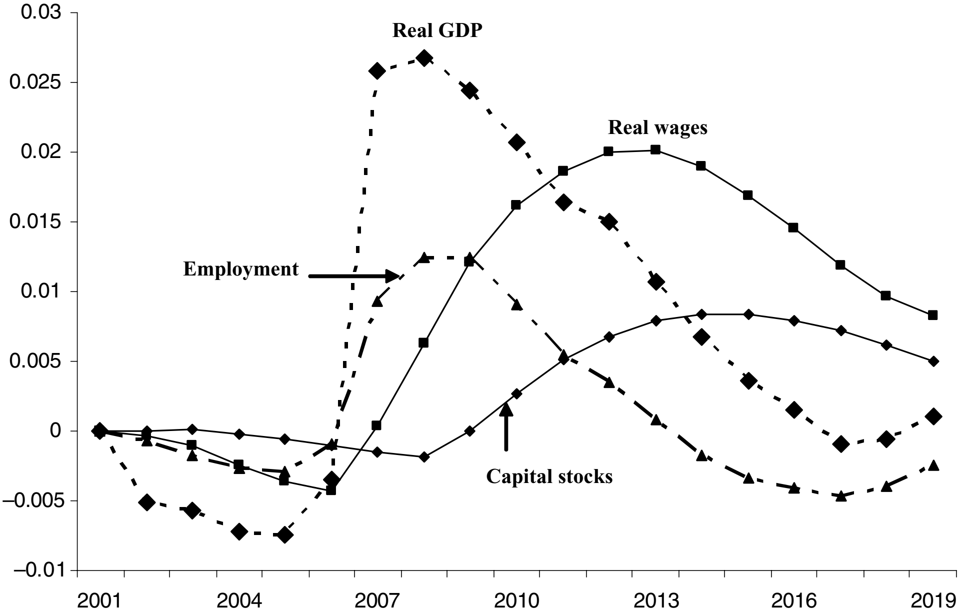

Figure 3 National macroeconomic impacts (% change relative to forecast).

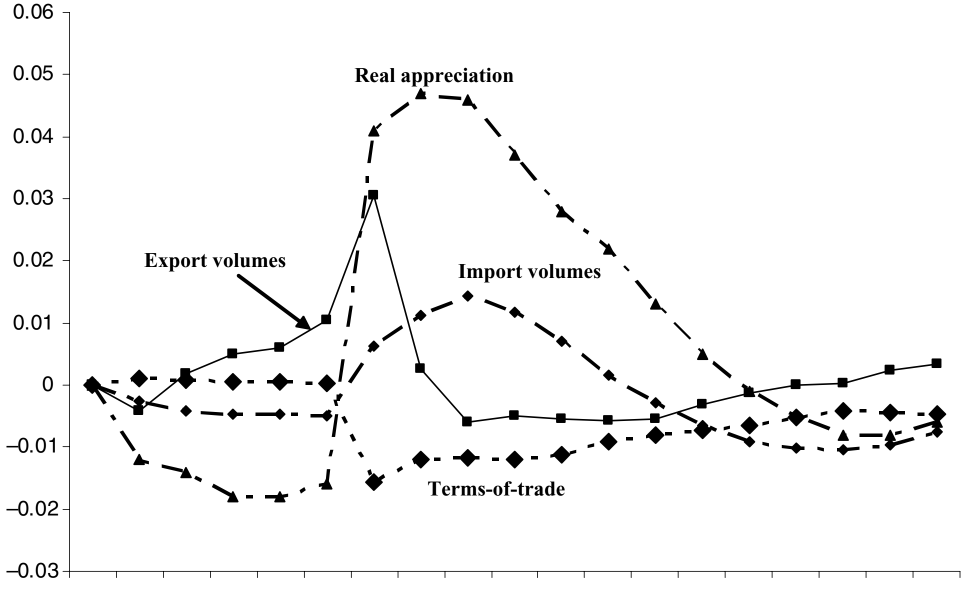

Figure 4 National macroeconomic trade-related variables (% change relative to forecast).

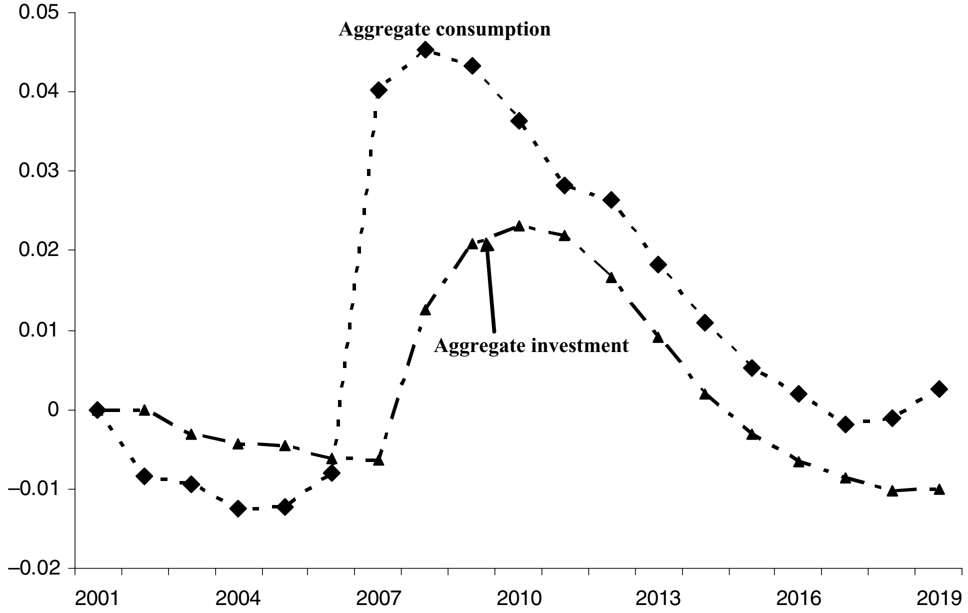

Figure 5 National aggregate consumption and investment (% change relative to forecast).

rises. From 2007, real wages rise, inducing further cost increases. The output effect is relatively large because imports replace domestic goods in this import-competing sector (Figure 2).

The technological improvement arising from improved weed management induces a real appreciation of the Australian currency, measured as the percentage change in the GDP deflator (i.e., domestic prices) minus the percentage change in foreign prices, denoted by the import price index (Figure 4), given that the nominal exchange rate is exogenous and unchanged. As a consequence of domestic production costs rising relative to foreign costs, mining, an export-oriented sector that does not use crop inputs, is also a loser (Figure 2). Since export volumes rise and exports face finitely elastic global demand (whereas we assume that import supply is perfectly elastic), there is a decline in the terms-of-trade in 2007. The reduced price penalties for contaminated wheat and barley are small in comparison with price falls arising from movements down the export demand curves in 2007. In 2008 and 2009, there are several reasons why the deviation in export volumes declines relative to 2007: an increasing share of domestic product is sold within Australia, as aggregate consumption and investment increase (shown in Figure 5), so that the deviation in export supply falls; mining output gradually declines as mining investment falls behind base forecast levels; and the direct benefit of the weed management program diminishes over time.

Next, we consider the impact of the weed control scenario on Australia's aggregate consumption and investment (Figure 5). The technological improvement initially raises rates of return relative to forecast. The diminishing direct impact of the weed management program and a gradual increase in capital stocks leads to a decline in the rates-of-return deviation after 2010. By 2019, investment has fallen temporarily below the base forecast. As is evident from Figure 3, capital stocks are still above the base forecast in this year. Investment can be funded either by domestic income or by increasing the trade deficit. In the latter case, increased interest payments on net foreign liabilities reduce the disposable income that feeds into the consumption function. That is, we base the consumption function on nominal GNP rather than nominal GDP. Since we keep real government expenditures at base forecast levels in the policy simulation, the net present value of changes in real aggregate consumption (discounted at 7 per cent) is our measure of welfare. This amounts to $700m summed over the years from 2002 to 2019 (expressed in 2005 dollars). GNP includes exports, but not imports, while domestic consumption includes imports but not exports, so that real consumption is the preferred welfare indicator when there are terms-of-trade fluctuations.

3.2 Regional effects

We now examine the impact of the weed control scenario on aggregate consumption at the regional level. Figure 6 shows the path of aggregate consumption relative to the base forecast for four of the directly affected regions. In each case, there is an increase in 2007 and a gradual diminution relative to the base forecast thereafter. Western Australia is the most intensive of all states in both winter crop production and mining, and therefore relatively intensive in both the winning and losing sectors. From 2007 to approximately 2012, the benefits of improved weed management dominate the state impact. Mining investment declines as capital shifts into cropping, and the negative impact on mining becomes more prominent in the outcome in later years. As

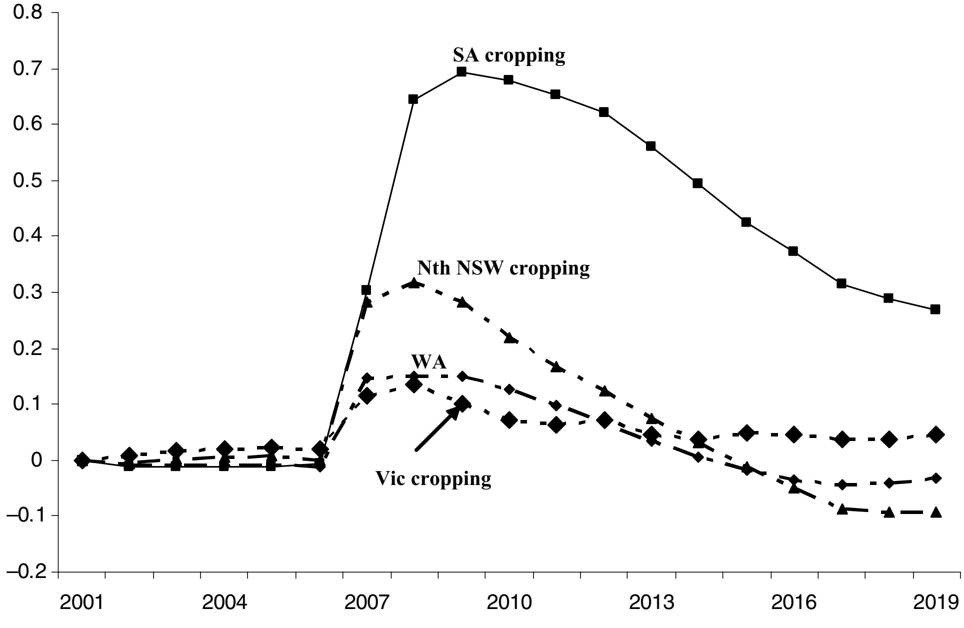

Figure 6 Aggregate consumption in selected cropping regions (% change relative to forecast).

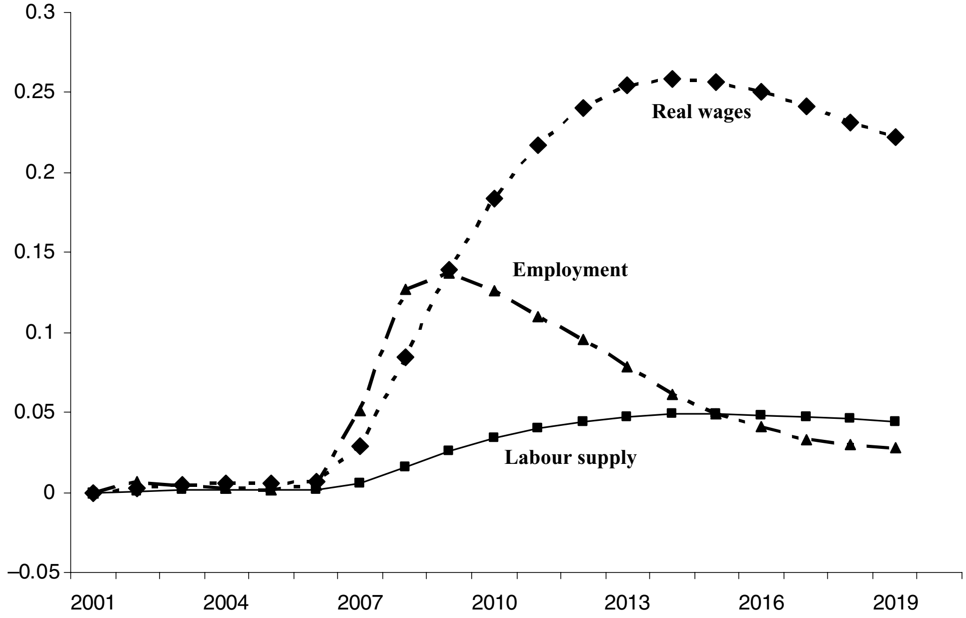

Figure 7 Labour market in South Australian cropping (% change relative to forecast).

mining output recovers slowly (Figure 2) and crop output declines (Figure 1) with the diminishing weed management benefit, both income and aggregate consumption are below forecast by 2015. In South Australian cropping (including all South Australia's statistical divisions other than Adelaide and Outer Adelaide), Victorian cropping (the combined statistical divisions of Western District, Central Highlands, Wimmera, Mallee, Loddon and Goulburn Valley) and Northern New South Wales cropping (combining Northern and North West statistical divisions), the losing sectors play little part in the overall impact. Consequently, the incomes and aggregate consumption of these regions reflect mostly the direct impacts of the weed control scenario.

The modelling output allows us to examine any of the 11 regions in detail. We confine our discussion to South Australian cropping. Figure 7 shows the labour market in South Australian cropping, in which cropping accounts for 9 per cent of total income. Employment increases in 2009 to 0.14 per cent above the base forecast, equal to an additional 200 jobs. Real wages rise continuously until employment and labour supply intersect in 2015: the real wages peak is 0.25 per cent above the base forecast, which compares to the national peak shown in Figure 3 of 0.02 per cent. Real wages start to decline in subsequent years, but are still 0.2 per cent above the base forecast in 2019. This reflects a sustained increase in the capital-to-labour ratio (Figure 8).

Figure 8 shows aggregate labour and capital, plus real gross regional product (real GRP) for South Australian cropping. Between 2002 and 2006, real GRP is slightly below the base forecast. This is because the R&D phase is treated as a small increase in intermediate input requirements (i.e., technological deterioration) in the relevant crop sectors during this time. With the benefits of the program arising in 2007, real GRP increases to 0.29 per cent above the base forecast. Capital stocks adjust more slowly

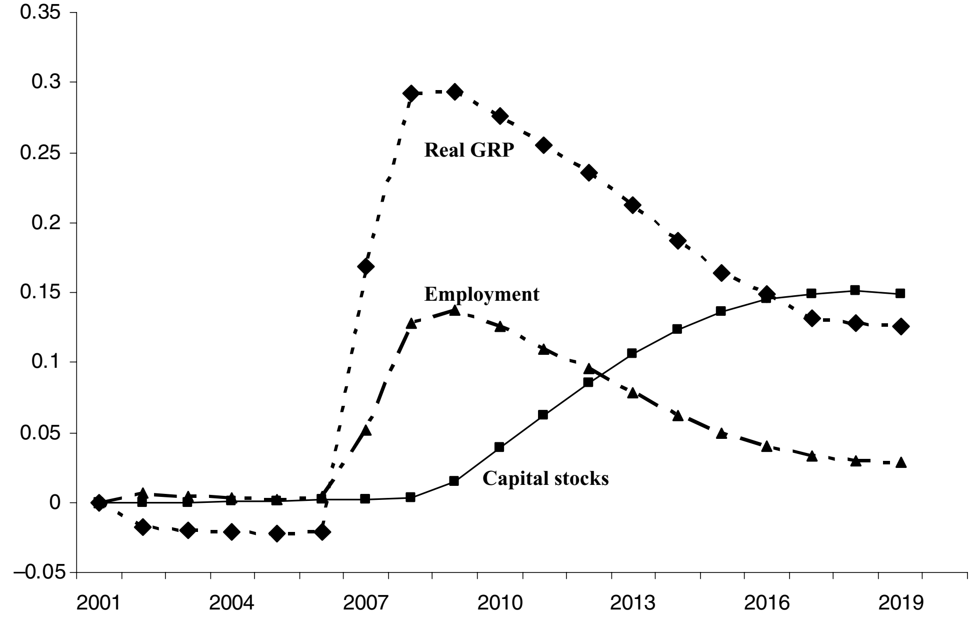

Figure 8 Real income, employment and capital stocks in South Australian cropping (% change relative to forecast).

than employment. The imposed linear decrease in technological gains arising from the program is the largest contributor to changes in real GRP after 2007, but through a sustained increase in capital stocks, real GRP remains above forecast in 2019.

Aggregate consumption in South Australian cropping peaks at 0.7 per cent above the base forecast in 2009 (Figure 9). Investment rises above forecast only following the realisation of reduced production costs in winter crops in 2007. Despite the declining benefit relative to forecast after 2007, aggregate investment continues to rise relative to forecast as investment responds to previous period changes in rates of return. We have used static rather than rational expectations in the theory of investment in the model, because we assume that producers do not anticipate the benefit relative to forecast of the R&D program. Aggregate investment and consumption in SA cropping persist slightly above forecast in 2019, indicating that the temporary benefit has regional economic consequences that last beyond the period of direct benefit.

3.3 Sensitivity of welfare outcome to different assumptions

The welfare benefits of weed control calculated using a dynamic model will vary with the magnitude and duration of the R&D expenditure and the assumed effectiveness and duration of the new weed control technology. How soon the benefits occur after the R&D program commences will also influence the welfare calculation. In addition, if the effectiveness of weed management varies between regions because of differences in the growing environment, the dynamic TERM model provides a tool for examining the inter-temporal and regional implications of such differences.

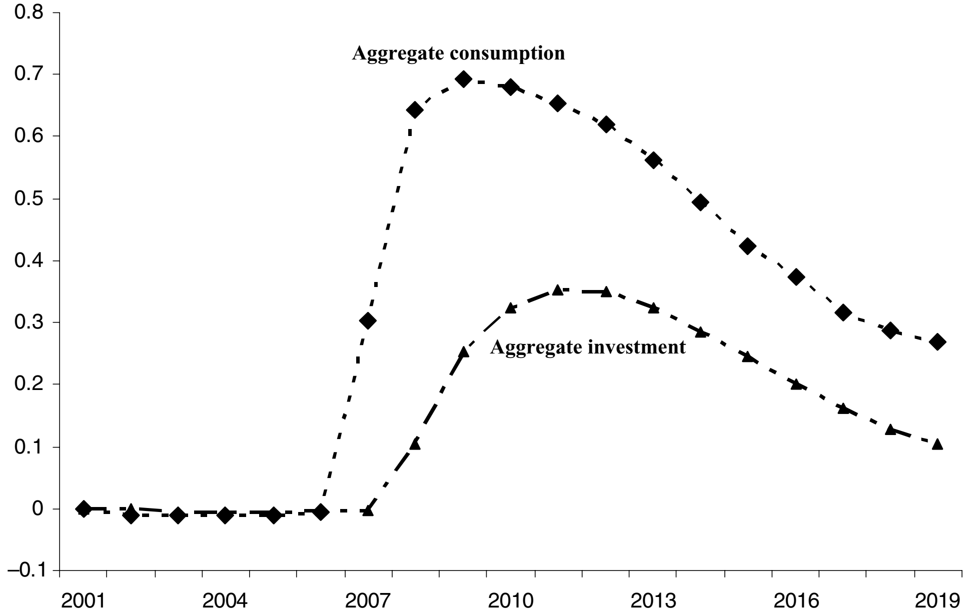

Figure 9 Aggregate consumption and investment in South Australian cropping (% change relative to forecast).

With the link between investment and capital accumulation, following the multi-sectoral dynamic approach pioneered by Dixon and Rimmer (2002), adjustment costs can be captured. This approach may be potentially useful in further applications concerning plantation crops reliant on initial investments that produce multiple years of cropping income. Should an extreme event such as a weed or disease infestation lead to plantation destruction, the dynamic CGE approach provides a unique means of fully accounting for the welfare loss arising from the event, as a shock to the model can depict the full capital stock value of the loss.

The forecast baseline also influences the welfare impact of our R&D scenario. Were the weeds eradication campaign to proceed in sectors for which world demand is falling over time, the welfare benefit could diminish or even become negative. In a dynamic model, we do not assume that labour and capital can be moved instantly and without cost to other activities. Therefore, R&D in a declining industry, even if yielding direct benefits, could result in a welfare loss relative to forecast.

Parametric choice within the model may also influence results, though to a lesser extent. For example, if we increase the export demand elasticities for winter crops from –4.0 to –8.0, the terms-of-trade decline in 2007 will shrink from –0.016 to –0.008. Exports account for 22 per cent, and aggregate consumption 55 per cent, of GDP in 2007. The impact of doubling the relevant parameter will be to increase aggregate consumption by 0.003 per cent ($= 0.008 \times 0.22/0.55$) or less than \$20m, which is approximately one-tenth of the deviation in aggregate consumption in 2007.

4. Summary and discussion

Weeds are a major constraint in Australia's winter crop production. Although there have been several recent studies of the cost of weeds in winter crops (Jones *et al.* 2000, 2004), the dynamic CGE modelling approach adopted in this study adds further dimensions to the available economic information on the effects of weeds on agricultural production. Alston *et al.* (1995) noted that there was a strong case for the analysis of the general equilibrium impacts of agricultural research. Some impacts on non-agricultural production, which flow from the direct impacts in the agricultural sector, are readily understood. For example, food processing sectors benefit from reduced production costs and higher yields in cropping sectors. However, other effects are less obvious, particularly the negative impact on sectors facing substantial international competition, as the successful weed management program induces a real appreciation of the Australian dollar.

Different economic models provide different tools for estimating the economic costs arising from weed infestations. Partial equilibrium analysis depicts a short- to medium-term scenario in which factors of production are relatively immobile, whereas CGE analysis in a comparative static framework can represent different time horizons. In a short-run CGE setting, labour is mobile and capital stocks fixed. In a long-run setting, there is sufficient time for capital depreciation and investment in new capital to restore rates of return to pre-simulation levels. Nevertheless, despite not depicting an adjustment path, comparative static CGE analysis overcomes some of the limitations of partial equilibrium analysis, as productive resources may be diverted to other activities, while household consumers can adjust expenditure shares in response to changes in prices.

Alternatively, dynamic CGE analysis depicts a period-by-period path of adjustment. Based on the dynamic labour market theory implemented in this study, initial regional adjustment is more through changes in employment than wages. While wages adjust year-by-year, regional differences in real wages may persist in the long run in a policy scenario, allowing significant differences to emerge in per capita incomes across regions. Capital stocks adjust gradually as industry investment adjusts to changes in rates of return.

Unlike comparative static analyses, in dynamic CGE analyses, the end point is not our primary concern. Indeed, we assume in our scenario that the extra R&D investment in weeds has ended its useful life before the final year of the simulation. That is, the costs and yield losses arising from weeds are the same by the year 2017 as in the base forecast. In this respect, dynamic CGE modelling potentially has greater realism than comparative static models. We are able to calculate the welfare benefit of the R&D effort as the discounted net present value of the deviation in household consumption from the base forecast. We also observe that reduced weed costs provide benefits that are concentrated in the regions with substantial plantings of winter crops. Sectors without direct impacts may lose though indirect losses, though these are proportionally smaller than direct effects.

Finally, we can compare the welfare benefit calculated by using the dynamic CGE model with the comparative static partial equilibrium equivalent. The equivalent direct benefit from Jones *et al.* (2004) for 2007 would be one-tenth of the total weeds cost, \$127.9m, falling away to zero by 2017. If we use the same direct costs and benefits as for the dynamic CGE approach, the discounted net present value of welfare amounts to \$371m, substantially less than the CGE-based \$700m. Part, but not all, of this difference reflects indirect benefits. In the dynamic forecast baseline of the CGE model, winter crops' output in 2007 is 12 per cent higher than in 2002, and is 72 per cent higher by 2019. If we impose an annual output growth on the crop sectors to reflect this, the revised welfare calculation based on Jones *et al.* (2004) rises to \$432m. The gap between this figure and the CGE-based \$700m is the more appropriate indicator of the indirect benefits of the R&D effort. This is \$268m or almost two-thirds the value of the direct industry benefits.

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Appendix: dynamic regional labour market theory

The regional labour market adjustment mechanism, in levels, is given by

$$\left(\frac{W_t^r}{Wf_t^r} - 1\right) = \left(\frac{W_{t-1}^r}{Wf_{t-1}^r} - 1\right) + \alpha\left(\frac{EMP_t^r}{EMPf_t^r} - \frac{LS_t^r}{LSf_t^r}\right) \tag{1}$$

In Equation (1), if the deviation shock weakens the labour market in region r and period t relative to forecast, real wages W_t^r in deviation will fall relative to forecast Wf_t^r. In addition, there will be an initial enlarged gap between labour market demand EMP_t^r and supply LS_t^r, relative to forecast levels $EMPf_t^r$ and LSf_t^r. In successive years, the gap between demand and supply will gradually return to forecast through a further decline in real wages. The speed of labour market adjustment is governed by α, a positive parameter.

The regional labour supply equation is

$$\frac{LS_t^r}{LSf_t^r} = \frac{(W_t^r)^\gamma}{\sum\limits_q (W_t^q)^\gamma S_t^q} \Bigg/ \frac{(Wf_t^r)^\gamma}{\sum\limits_q (Wf_t^q)^\gamma Sf_t^q} \tag{2}$$

The deviation in regional labour supply from forecast depends on the deviation in regional relative to national real wages from forecast. In Equation (2), $\sum_q (W_t^q)^\gamma S_t^q$ is a measure of labour responsiveness to real wages summed across all regions, where γ is a positive parameter and S_t^q is the share of region q in national employment. Should the deviation in real wages from forecast fall in a particular region relative to the situation nationally, this equation implies that labour supply in the particular region will fall, while in other regions it will rise. Combining Equations (1) and (2), adjustment in the labour market in a given region will initially occur via a combination of additional unemployment and lower (slowly adjusting) real wages. Unemployment will eventually return to forecast rates, with lower real wages. As real wages fall relative to the base case, the region's labour supply will also fall. Within this theory, long-run labour market adjustment occurs as a combination of inter-regional labour migration and changes in regional real-wage differentials.