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Regional economic impacts of a plant disease incursion using a general equilibrium approach*

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The present study uses a dynamic multiregional computable general equilibrium (CGE) model to estimate the micro- and macroeconomic effects of a hypothetical disease or pest outbreak. Our example is a Karnal bunt incursion in wheat in Western Australia. The extent of the incursion, the impact of the disease or pest on plant yields, the response of buyers, the costs of eradication and the time path of the scenario contribute to outcomes at the industry, regional, state and national levels. We decompose the contribution of these individual direct effects to the overall impact of the incursion. This might provide some guidance regarding areas for priority in attempting to eradicate or minimise the impacts of a disease or pest. The study also introduces a theory of dynamic regional labour adjustment in which economic events may lead to both real wage differentials and worker migration between regions.

Key words: CGE modelling, dynamics, plant disease.

1. Introduction

This study examines the regional and national economic impacts of a hypothetical outbreak of the fungus *Tilletia indica* (the causal agent of Karnal bunt) in wheat crops in the wheat belt of Western Australia. The work was initiated to provide a generic model to assist in analysing the regional economic impact of any exotic plant disease or pest incursion under new cost-sharing arrangements being developed for Australia between the government and plant industries. To fully assess the impact of an exotic disease or pest on a plant industry it is important to have a clear understanding of the potential regional economic impacts of an exotic incursion. Karnal bunt was used as the case-study disease for developing the generic model to assess the regional and national economic impacts of a hypothetical incursion.

Karnal bunt has minimal impact on crop yield but is considered a disease of political and quarantine importance (Stansbury and Pretorius 2001). First described in Karnal, Haryana, India in 1930, it spread to Afghanistan, Iran, Iraq, Lebanon, Nepal and Pakistan. Subsequently, it has been detected on continents other than Asia, starting

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with North America, in Mexico in 1972. More recently, it was detected in the USA in 1996 (Ykema *et al*. 1996) and South Africa in 2000 (Crous *et al*. 2001; Stansbury and Pretorius 2001). Since 1983, a number of nations have responded to the threat of disease with planting and seed industry quarantines and restrictions. The impact of Karnal bunt on yields is minimal. As only a small proportion of grains in a field is infected, the main problem is with the perceived quality rather than quantity of output. It is likely therefore that seed infected by the fungus will be downgraded or rejected by buyers.

There have been a limited number of estimates of the potential economic effects of Karnal bunt. Stansbury *et al*. (2002) modelled the risk of *T. indica* impacting on the wheat industry in Western Australia (WA). This work suggested that first detection of the pathogen could range from 4 to 11 years after the initial infection, with an economic impact of between 8 and 24% of the value of production in WA. Brennan *et al*. (2004) classified the costs associated with an outbreak of Karnal bunt as direct costs, reaction costs and control costs, and estimated the relative importance of each cost for a hypothetical outbreak in the European Union. Murray and Brennan (1998) estimated that the economic loss from the pathogen, should it become established across all of Australia's wheat-growing regions, would amount to $A491 million per annum.

We use the dynamic, computable general equilibrium (CGE) Monash Multi-Regional Forecasting (MMRF) model to examine the regional and national economic impacts of a Karnal bunt incursion. We have applied the methodology to a number of other hypothetical incursions affecting other crops in various regions. Our inputs into the model include the initial impacts of the incursion on output and access to export markets, the timeline of fighting and overcoming the disease, and the associated direct costs.

In the general equilibrium approach, the loss of jobs and declining investment in a particular industry following a disease outbreak may be compensated to some extent by the movement of labour and capital into other sectors over time. In this respect, the perspective offered by our dynamic CGE modelling differs from that of other approaches such as equilibrium displacement modelling (EDM). In EDM or other partial equilibrium frameworks, the distribution of gains between producers and other agents from given supply or demand shifts is estimated for a specific set of industries (see James and Anderson 1998; Zhao *et al*. 2003). Our CGE framework differs by examining impacts beyond the industry-specific level: it projects year-to-year impacts on national and regional aggregate consumption, and on other macro- and microeconomic measures.

The CGE approach uses an input-output database with a regional disaggregation that includes comprehensive costs and sales structures. These are important in estimating the contribution of different consequences of the disease (i.e., lost productivity, quarantine restrictions, additional crop spraying) to the overall outcome and, together with the sales structure of the industry, may be useful in devising strategies for dealing with disease outbreaks. We also weigh the contributions of different direct effects on the overall outcome. Given the regional and sectoral detail in the master database, we can apply the methodology to various plant disease outbreaks arising in particular crops and regions.

2. The model

Monash Multi-Regional Forecasting is a dynamic, multiregional CGE model of Australia (Naqvi and Peter 1996; Adams *et al*. 2002). In a specific application, it is computationally convenient to aggregate the model with the choice of aggregation determined by the focus of the study. This aggregation is prepared from the master database, discussed in Section 2.2. For the application reported here, we use a two-region aggregation of the master database, with WA and the rest of Australia (ROA) represented separately. In the sectoral dimension, we aggregate to 27 industries. One of these industries is the grains industry, which we assume uses the same inputs to produce either wheat or barley following a constant elasticity of transformation (CET) form. In total, there are 28 commodities, with the remaining 26 industries each producing a unique commodity.

In the regional dimension, the model also includes top-down detail of the statistical divisions of the state in which the outbreak occurs. A specific modification for this project allows us to ascribe productivity shocks at the level of statistical divisions. This is useful, given that a specific substate region (the wheat belt) is affected by the disease outbreak.

The theory of MMRF is similar to that in national dynamic CGE models such as MONASH (Dixon and Rimmer 2002). Each industry in MMRF selects inputs of labour, capital and materials to minimise the costs of producing its output. The levels of output are chosen to satisfy demands and demands reflect prices and incomes. Investment in each industry reflects rates of return and capital reflects past investments and depreciation. The main difference is in the regional dimension. In MMRF, there is a given industry in each of the two regions, instead of a single national industry. Commodity users in MMRF have in this specific aggregation three sources of supply (Western Australia, the rest of Australia and imports) instead of two (domestic and imported) as in MONASH. MMRF has a national government, and a government and household in each region instead of having a single government and a single household.

Regions in MMRF are specified as separate economies, linked by trade. MMRF imposes a fixed exchange rate and free trade between regions, and common external tariffs. In this sense, MMRF remains a national, rather than international, model. This means that behaviour in foreign markets is determined outside the model (i.e., exogenously). In dynamic analysis, MMRF is run in two modes: forecasting and policy. In forecasting mode, it takes as inputs forecasts of macro and trade variables from organisations such as Access Economics (2003) and ABARE (2003), together with trend forecasts of demographic, technology and consumer-preference variables. It then produces detailed forecasts for industries, regions and occupations. In policy mode, it produces deviations from forecast paths in response to shocks relevant to the hypothesis being explored, such as changes in taxes, tariffs, technologies, world commodity prices and, in agriculture, disease outbreaks.

2.1 Key assumptions

Computable general equilibrium models such as MMRF can be run under many different sets of assumptions concerning macro- and microeconomic behaviour. The key general assumptions underlying our simulation follow. In running the model dynamically, we compare year-by-year a deviation simulation containing the scenario being studied with a business-as-usual (base case) forecast simulation.

2.1.1 Public expenditure and taxes

We assume that the disease outbreak makes no difference to the path of real public consumption. However, adjustments in income tax rates compensate for changes in government revenue and outlays associated with changes in the level of economic activity.

2.1.2 Labour market

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

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

The interpretation of (1) is that 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.[1]

The regional labour supply equation is:

$$\frac{LS_t^r}{LSf_t^r} = \frac{(W_t^r)^\gamma}{\sum_q (W_t^q)^\gamma S_t^q} \Bigg/ \frac{(Wf_t^r)^\gamma}{\sum_q (Wf_t^q)^\gamma Sf_t^q}. \quad (2)$$

The deviation in regional labour supply from forecast depends on the deviation in regional, relative to national, real wages from forecast. In (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 (1) and (2), adjustment in the labour market in a given region will initially occur through a combination of additional unemployment and lower 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

[1] Peter Dixon of the Centre of Policy Studies devised the regional labour market adjustment theory.

fall. Within this theory, long-run labour market adjustment occurs as a combination of interregional labour migration and changes in regional real-wage differentials.

2.1.3 Rates of return on industry capital stocks

In simulations of the effects of shocks, MMRF allows for short-run divergences in the ratios of actual to required rates of return from their levels in the base-case forecasts. Short-run increases/decreases in these ratios cause increases/decreases in investment. Movements in investment are reflected with a lag in capital stocks. These adjustments in capital stocks gradually reduce initial divergences in the rate of return ratios.

2.1.4 Production technologies

MMRF contains variables describing primary-factor and intermediate-input-saving technical change in current production, input-saving technical change in capital creation, and input-saving technical change in the provision of margin services (e.g., transport and retail trade). In our simulations, all these variables are held on their base-case forecast paths except for the scenario-specific shocks concerning wheat in Western Australia.

2.2 The database

Using a CGE approach to examine different hypothetical disease incursions at the regional and national level requires highly disaggregated regional input-output databases. The master database used to prepare regional aggregations for specific projects is based on the published national input-output table (ABS 2001). For this study, this table has been disaggregated in both sectoral and regional dimensions. The sectoral detail now includes many agricultural commodities not available in published ABS data. The regional dimension includes input-output tables for each of 57 statistical divisions in Australia. Horridge *et al*. (2003) details the sources of the master database, an outline of its preparation, and the methodology used to devise interregional trade matrices to connect the input-output databases of each region.

2.3 Assumptions concerning direct impacts

In estimating economic effects, we consider how widespread the disease is at the time of first detection. Murray and Brennan (1996) have outlined four different potential outbreak scenarios. In their case 1, the outbreak is small and isolated, with a high likelihood of disease containment being achieved through prohibition of wheat growing on affected farms for several years. Case 2 concerns a more scattered outbreak that could potentially be contained. In case 3, there is a wide distribution of disease in a region or district. In case 4, the disease is widely distributed throughout Australia. There are many areas of Australia's wheat growing regions where Karnal bunt would establish and spread; the climatic suitability for this pathogen of different regions in Australia has been determined by Murray and Brennan (1998) and Stansbury and McKirdy (2002).

Our base-case scenario for this study is pessimistic, in that we assume a relatively widespread outbreak; a case 3 scenario under the classification outlined by Murray and Brennan (1996). In reality, we might expect an outbreak to be detected in isolation, and therefore to be relatively easy to manage. However, as is evident in what follows, economic losses through quarantine measures are likely to be much greater than disease management and eradication costs during the hypothesised quarantine and eradication program. We need to assume the direct year-to-year impacts of a hypothetical incursion in order to run the dynamic CGE model. These include additional research and administration costs arising from fighting the disease and spraying costs incurred by the industry and public bodies. In addition, we need to estimate the impact of the incursion in terms of lost productivity or downgrading (actual or perceived) of quality. Quarantine restrictions in overseas' markets are particularly important for crops that are largely exported. Finally, there is the question of how many years it takes to eradicate a disease and restore lost markets.

In our assumed outbreak scenario, fighting the disease raises the input costs for virtually all Western Australian wheat farmers, as we assume that the scattered nature of the incursion puts all wheat farms in the state at risk, and therefore in need of fungicide applications. The supply side of the model contains shifters that allow us to shock different parts of the cost structure, including intermediate inputs and primary inputs. We increase specific intermediate-input requirements to depict the effect of additional fungicide requirements, estimated as $A9 million (approximately 0.4% of total production costs). We also assume that there is a yield loss of 0.1 per cent within the wheat belt (based on Brennan *et al*. 2004), ascribed through a primary-factor technology shock.

On the demand side, we assume two different adverse effects. The first is a perceived reduction in the quality of wheat, which lowers the price. The second effect is lost export markets. We assume that following the hypothetical outbreak in 2005, all Australia's wheat ports are affected because those foreign nations that prohibit the imports of wheat infected by Karnal bunt will temporarily ban all Australian wheat. This blanket ban lasts for 3 months.[2] We assume there is little scope for catch-up sales in the remainder of the year so that, outside Western Australia, export demand shrinks by 10 per cent. This is based on 40 per cent of total exports being sold to nations who ban wheat from sources with Karnal bunt outbreaks, with the ban on wheat produced outside Western Australia lasting for one quarter of a year. In Western Australia, we assume that markets banning wheat from regions with Karnal bunt outbreaks will maintain the ban until the disease has been eradicated in the state.

In our analysed scenario, export demand for wheat shipped from Australian ports outside Western Australia is fully restored in 2006. The ban on Western Australian wheat continues. Even if Karnal bunt is confined to the wheat belt, the ban effectively extends to the entire state because wheat originating in the wheat belt may be shipped through any of the state's grain ports. As wheat varieties differ between states, we allow imperfect substitution of wheat between the eastern states and Western Australia, for

[2] This assumption of the duration of bans on wheat from Australia is supported by an incident in February 2004 in which an importing country rejected wheat from Australia, incorrectly asserting that it was infected with Karnal bunt. A number of markets subsequently questioned the status of all Australian wheat, irrespective of state boundaries. Tender negotiations were suspended for two weeks in the case of one country. These did not resume until extensive tests confirmed that Karnal bunt was not present anywhere in Australia.

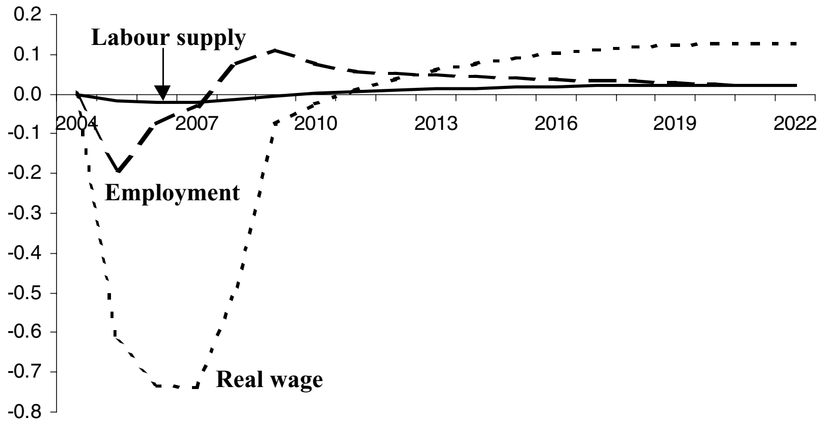

Figure 1 Effects of disease outbreak on Western Australian labour market (% deviation from baseline).

domestic users. In our hypothetical scenario, quarantine restrictions, reduced yields and additional production costs continue in Western Australia until 2010, and export demand is not fully restored until the following year.

3. Results and discussion

3.1 Disease outbreak and quarantine phase: 2005–2009

The labour market theory of this version of MMRF operates at the regional level. Therefore, we begin with the impact of the scenario at the state macroeconomic level. Figure 1 shows the impact of the scenario on the labour market variables explained in Equations 1 and 2. Initially, the adverse shock of the Karnal bunt scenario drives down both employment and regional wages in Western Australia. Employment falls by 0.22 per cent (as measured by industry wage-bill weights) or 2200 jobs in 2005 relative to the base case.[3] In years subsequent to 2005, real WA wages decline further. This provides a stimulus for WA sectors other than grains, and reduces the gap between WA labour supply and demand.

The reduction in employment is explained by two factors. First, WA aggregate expenditure moves away from investment (as a result of a decline in rates of return on capital following the disease outbreak and resultant loss of export markets) and away from consumption towards exports and import replacement (Figures 2 and 3). Second, there is a reduction in WA terms-of-trade (i.e., the price of exports divided by the price of imports, for both interstate and international trade) (Figure 4).

The switch in the composition of WA expenditure reduces employment in the short run at any given wage because export and import replacement activities are less

[3] As many farmers are owner-operators, they will suffer a drop in imputed wages that far exceeds the 0.14% decline in real WA wages overall. Therefore, actual job losses in agriculture would be smaller than implied by our assumption that all wages in WA deviate from forecast by an equal percentage.

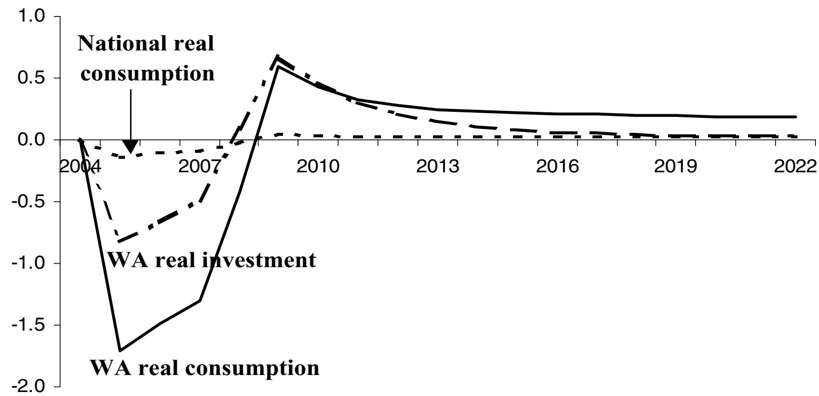

Figure 2 Effects of disease outbreak on Western Australian investment and consumption (% deviation from baseline).

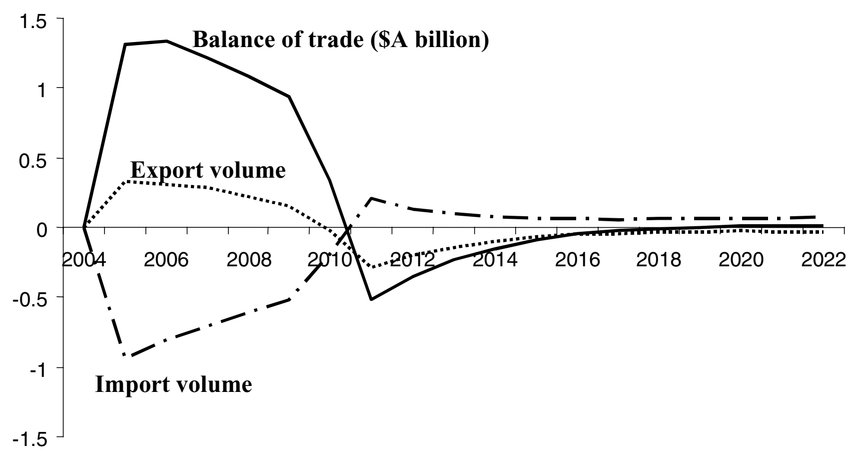

Figure 3 Effects of disease outbreak on Western Australian trade balance and volumes (% deviation for exports and imports; $Abn deviation for balance of trade).

labour-intensive than investment and consumption activities. The terms-of-trade reduction reduces employment in the short run through the marginal product/wage relationship:

$$MP_L(K/L) = (W/P_c) \times (P_c/P_g). \quad (3)$$

In Equation 3, the value of the marginal product of labour to employers, that is MP_L times the price of *GSP* (P_g, where *GSP* is gross state product) is equated to the wage rate (W). In (3), we write this relationship as the product of two ratios. The first is the real wage as seen by workers and the second is the consumer price index (P_c) divided by the price deflator for *GSP* (P_g). With a terms-of-trade decline, P_c/P_g increases because P_c includes the prices of imports but not exports, whereas P_g includes the

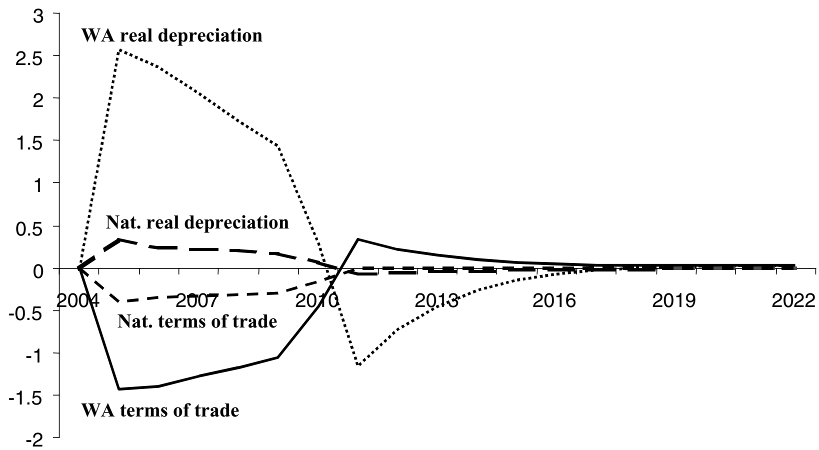

Figure 4 Effects of disease outbreak on real exchange rates and terms-of-trade (% deviation from baseline).

prices of exports but not imports. Under our assumption of sluggish adjustment in the real wage (i.e., little short-run change in W/P_c), an increase in P_c/P_g causes an increase in MP_L, requiring an increase in the capital/labour ratio (K/L). Because K (i.e., capital plus land) is fixed in the short run, L must fall.

As it weakens the terms-of-trade, the direct loss of export markets reduces domestic absorption within Western Australia. The effect (reflected in WA real exchange rate shown in Figure 4) facilitates an increase in exports for commodities other than wheat, and inhibits imports (Figure 3). Overall, the changes in export and import volumes are sufficient for the trade balance to move towards surplus, by \$A1.3 billion (Figure 3). This seemingly paradoxical result arises because export volumes of all commodities other than wheat increase during the period when at least some Australian wheat is banned in some export destinations.

For several years from 2005, WA investment slowly recovers relative to the base case, as resources move to other sectors. At the same time, the terms-of-trade gradually improve (Figure 4). This is partly because investment and consumption move back towards the base case, increasing WA domestic absorption and thereby decreasing the volume of commodities available for export. As export volumes decrease, export prices increase, reflecting finite export demand elasticities (i.e., an elasticity of −4 indicates that for each 4% decrease in export volumes, there is a 1% increase in export prices).

Private consumption is reduced in 2005 by 2.0 per cent (approximately \$A1.1 billion), considerably larger than the loss in real GSP of 0.14 per cent (Figure 5). This gap between lost income and lost consumption is explained mostly by the terms-of-trade decline. As shown in Figure 4, WA terms-of-trade falls in 2005 by 1.5 per cent. The Australia-wide terms-of-trade are also shown, with the WA contribution accounting for virtually all the decline. With WA international plus interstate exports in 2005 being forecast at \$A53 billion, a terms-of-trade fall of 1.5 per cent is equivalent to a loss in disposable income (and therefore consumption) of \$A800 million ($= 53 \times 0.015 \times 1000$).

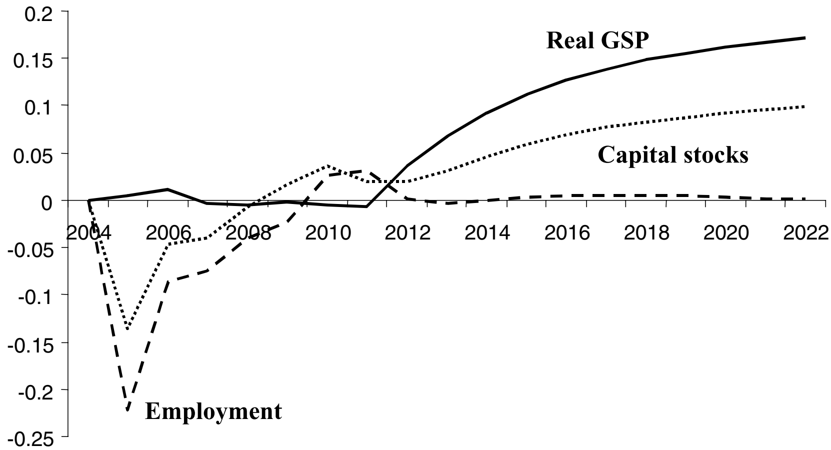

Figure 5 Effects of disease outbreak on Western Australian income, employment and capital stocks (% deviation from baseline).

After 2005, real wages continue to fall, allowing the gap between employment and labour supply to close, so that by 2008, with no remaining gap relative to forecast, there is no further downward pressure on WA real wages (Figure 1). Without elimination of the disease outbreak and without removal of associated overseas' quarantine restrictions, we would expect WA real wages to remain below the base case, but without further decline. The state's share of national labour supply would also stabilise below base-case levels, dragged down by the real wage.

Figure 6 shows the impact of the disease outbreak on WA wheat output and exports. The grain growing regions of WA are dominated by mixed farm enterprises. Therefore, scope exists for switching from one crop to another or moving production away from grains into livestock. Figure 7 shows that there is a small degree of switching from grain

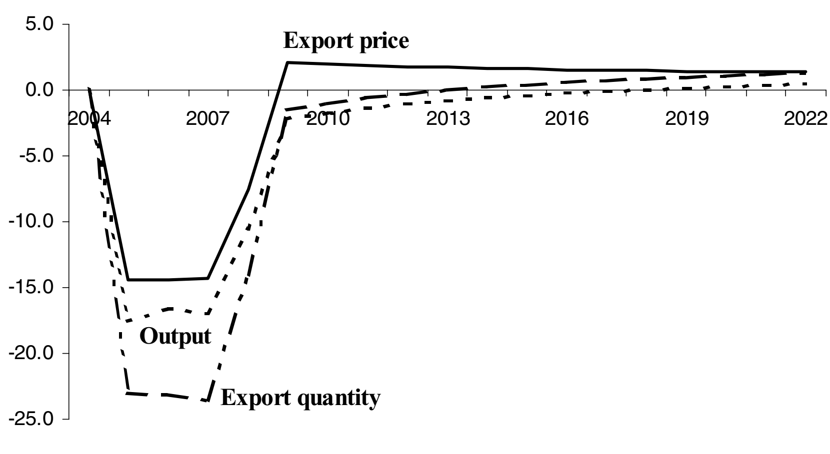

Figure 6 Effects of disease outbreak on Western Australian wheat output, export volumes and export prices (% deviation from baseline).

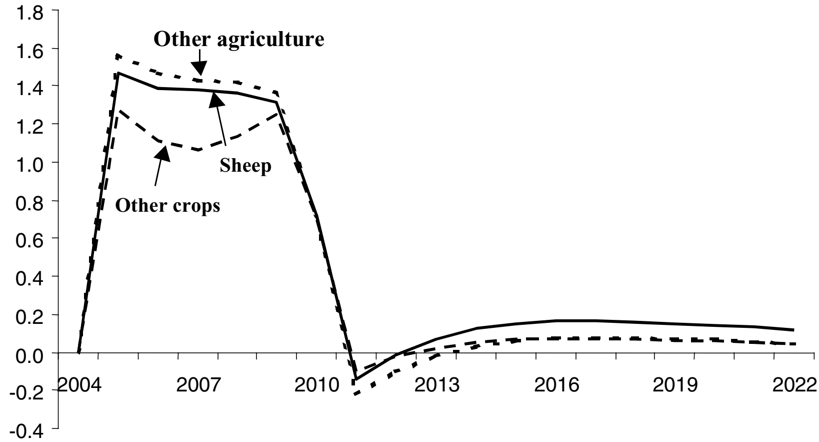

Figure 7 Effects of disease outbreak on Western Australian agricultural outputs (% deviation from baseline).

production to other broadacre activities between 2005 and 2008. The switching only partly compensates for lost incomes in grain production. Within grains production, value-share of output of barley in WA in 2006 is 20 per cent in the base forecast, rising to 27 per cent in the deviation scenario in 2006. We assume within the model that the transformation parameter is 2, so that for each 1 per cent rise in the output price of barley relative to the composite grains price, output of barley rises by 2 per cent more than composite grains output. Additional substitution possibilities that exist between wheat and various other broadacre crops are not represented in this model.

At the statistical division level, the disease outbreak has a severe effect on the wheat growing regions of WA. Figure 8 shows the real output of the wheat belt (real gross regional product or real GRP) dropping by between 3 and 4 per cent until the disease

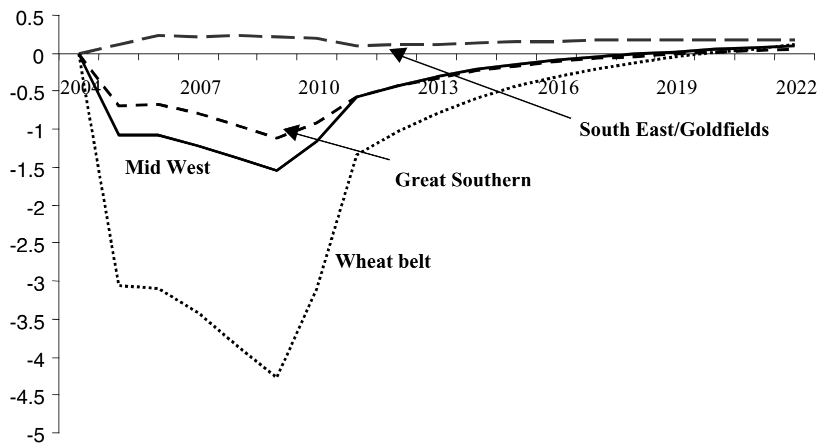

Figure 8 Effects of disease outbreak on real incomes of main Western Australian wheat-growing regions (% deviation from baseline).

is eradicated. The impact of the disease outbreak on the real disposable income of this region is larger than the impact on real GRP, because of the adverse terms-of-trade effect. In the wheat belt, wheat accounts for approximately 25 per cent of real income. In the scenario, the export price of wheat in WA falls by approximately 15 per cent (Figure 6). This fall is equivalent to a cut in real disposable income in the wheat belt of 3.75 per cent (= 0.25 × 15%). This compares with a state-wide decline in the terms-of-trade in 2005 of 1.5 per cent. Combining the decrease in real output with the terms-of-trade decline, the wheat belt's spending power decreases by approximately 7 per cent until eradication of the disease. Our model allows for the movement of output from wheat to barley without changes in inputs, some diversion of grains into livestock inputs in response to changing relative prices and reallocation of productive resources to other activities over time. But such measures can only partly alleviate the negative impact of the disease on the region. The other regions shown in Figure 8 are not as severely affected, because wheat's contribution to local income is less: 12.5 per cent in the Mid-West, 5.7 per cent in Great Southern and 2.0 per cent in South-East/Goldfields.

3.2 Decomposition of direct impacts

One way of assessing the impact of each of our assumptions on the simulated outcome is to decompose the shocks to evaluate each contribution to the overall result. We do this for a single year, 2005, in which the greatest losses occur. The columns in Table 1 decompose individual effects. For example, the column labelled 'spray/yield' shows the impact of additional spraying costs and reduced yields. Our database shows that over 95 per cent of WA wheat is exported. Hence, quality downgrades and quarantine

Table 1 A decomposition of the impacts of the Karnal bunt outbreak in 2005, percentage change from 2005 baseline

	Total	Spray/ yield	Quality downgrade	WA wheat: foreign quarantine	ROA wheat: foreign quarantine
National					
Real GDP	−0.02	0.00	−0.01	−0.01	0.00
Employment	−0.02	0.00	−0.01	−0.01	0.00
Capital stocks	0.00	0.00	0.00	0.00	0.00
Aggregate consumption	−0.18	0.00	−0.08	−0.08	−0.02
Aggregate investment	−0.13	0.00	−0.04	−0.04	−0.03
WA					
Real GSP	−0.14	0.00	−0.07	−0.08	0.00
Employment	−0.23	0.00	−0.11	−0.12	0.01
Capital stocks	0.00	0.00	0.00	0.00	0.00
Aggregate consumption	−2.12	0.00	−1.05	−1.12	0.05
Aggregate investment	−1.16	0.00	−0.59	−0.60	0.03
Wheat output	−12.9	−0.1	−5.9	−7.0	0.1
Wheat export volume	−17.6	−0.1	−8.4	−9.5	0.4
Wheat output price	−17.2	−0.1	−8.5	−8.7	0.1

WA, Western Australia; ROA, rest of Australia; GDP, gross domestic product; GSP, gross state product.

restrictions on WA wheat in foreign markets dominate economic losses. For example, these two columns account entirely for the decline in WA aggregate consumption and investment relative to forecast, with a small positive effect from the temporary quarantine restrictions on interstate wheat exports.

3.3 Disease elimination and market restoration phase: 2010 onwards

The elimination of the disease in 2010 brings small intermediate and primary input productivity improvements and, more importantly, a partial restoration of export markets that is completed in 2011. Investment in WA surges above the base case in 2010, and rises further with additional favourable demand shocks in the following year (Figure 2). The jump in investment induces a rise in employment well above labour supply in the state, so that unemployment is reduced relative to forecast (Figure 1). Figure 3 shows the terms-of-trade improvement arising in 2011. From 2012 onwards, investment dampens and employment falls slightly. As long as employment remains above labour supply, there is upward pressure on regional wages, so that by 2022, real wages are moving ever closer to forecast.

Aggregate consumption jumps above the base case with full restoration in 2011 and remains there for the rest of the simulated time horizon. This is caused by the balance of trade surplus from 2005, in which WA has a compensating accumulation of foreign financial capital (relative to the base case). With employment and real wages in WA merging towards base-case levels after 2013, aggregate consumption persists above forecast, reflecting reduced debt-servicing payments to foreigners. As an indicator of the national welfare loss arising from the disease outbreak, the present value of the deviation in national real aggregate consumption (as shown in Figure 2, discounted at 6%) is −$A1280 million (including all years to 2022). WA accounts for approximately half of national wheat exports. We can compare this welfare loss with the much larger annual partial equilibrium loss of $A491 million calculated by Murray and Brennan (1998), for the case in which all Australian wheat is subject to quarantine restrictions in foreign markets. A ban for a comparable period (i.e., 6 years) based on their annual figure would amount to $A1473 million (i.e., $491 \times 0.5 \times 6 = 1473$). We would expect our CGE calculation to be smaller than the partial equilibrium estimate as there is sufficient time for a significant movement of labour and capital to other activities.

Figure 5 shows the impact of the scenario on WA aggregate factors of production and real *GSP*. Industries not affected by the direct adverse effects of the scenario in WA benefit from a prolonged period of lower real wages before and after the restoration. This induces additional investment in these industries, so that real *GSP* and capital rise above base-case levels. This in part results from compositional change, with resources moving to relatively capital-intensive mining.

4. Conclusion

This analysis of the economic impacts of a plant disease incursion indicates the potential of a dynamic CGE model to assist in quantifying the regional and national effects of exotic plant diseases or pests as part of a government and plant industries cost sharing agreement. CGE modelling provides information relevant to the issue of public versus industry funding that is not necessarily available from a comparative static and/or partial equilibrium approach. In the case of a hypothetical Karnal bunt outbreak, expected foreign quarantine restrictions dominate economic losses. Therefore, isolation of the disease, if possible, and restrictions on movements of machinery and wheat within the affected area may be more cost-effective than elimination of the disease. In the scenario described in the present paper, eradication may be impractical as the pathogen is scattered over a wide area on detection.

Generally, the need to eradicate rather than confine the disease becomes stronger as productivity losses increase relative to quarantine losses. For example, the impacts of foreign quarantine measures against grape exports would be small compared with productivity losses in the event of an outbreak of Pierce's disease that would lead to the widespread removal of vine stock in a wine-producing region (CAB 2002).

At the regional level, the dynamic CGE approach provides new insights. For example, we can readily distinguish between real output and real disposable income because we capture the impacts of changes in the terms-of-trade. As part of this study, we introduced a regional labour market adjustment theory with the effect that a persistent damaging incursion in an industry would result in a long-run lower real wage in the adversely affected region, combined with lower labour supply. The negative impact would result eventually in interregional movements of labour. In addition, adjustments to capital stocks over time restore rates of return on capital to baseline levels. Consequently, welfare effects arising from an incursion are spread as a result of lower wages beyond the industry of origin, and interregional migration and reallocation of investment beyond the region of the outbreak.

Our assumptions concerning factor mobility imply that we cannot use direct impacts on individual industries and regions as indicators of welfare. Even state-wide measures of welfare need qualification. While we could calculate the net present value of aggregate consumption relative to forecast in a region as a measure of welfare, this is confounded by interregional migration. Net present value measured at the national level remains the preferred welfare indicator.

In the case of any hypothetical incursion, we are able to vary the assumptions concerning the timeline of an outbreak, and associated costs arising from fighting the disease, and damage to the industry through lost output or lost markets. Whether losses occur via damage to productivity or damage to sales, the dynamic CGE approach provides a useful method of estimating industry, regional and national impacts.

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