H1N1 influenza and the Australian macroeconomy

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Abstract

Early 2009 saw the emergence of an H1N1 influenza epidemic that spread to eventually become a global pandemic. We might expect that the pandemic would have large temporary macroeconomic effects on highly affected regions. Here we estimate what those effects might be for Australia. Our analysis applies the MONASH-Health model: a quarterly computable general equilibrium model of the Australian economy. We simulate the effects of two H1N1 epidemics; the relatively mild 2009 outbreak and also a more severe episode. The analysis suggests that an H1N1 epidemic could have significant short-run macroeconomic effects.

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1. Introduction

Early 2009 saw the emergence of an H1N1 influenza (swine flu) epidemic that spread to eventually become a global pandemic: as of January 2010, there had been laboratory confirmed cases of swine flu in over 208 countries and, at least, 13,554 deaths (WHO 2010a).[1] At the same time (January 2010), the World Health Organisation declared that while H1N1 activity had peaked in most regions of the world, intense pandemic activity was still being observed in North Africa, Southern Asia, and parts of East and Southeast Europe, so the pandemic was ongoing at that time (WHO 2010b).

In Australia, there had been 37,562 confirmed cases of swine flu and 191 deaths by January 2010. But national influenza activity was low:

- influenza-like illness (ILI) presentation rates to General Practitioners[2] were below levels seen at the start of 2008 and 2009;
- ILI presentations to emergency departments remained steady;
- enquiries to the National Health Call Centre Network regarding ILI remained stable and were at low levels;
- absenteeism rates remained similar to levels seen at the end of 2007 (DHA 2010).

A measure of the relative severity of the epidemic in Australia is given by a comparison of two indicators. Relative to other southern hemisphere countries, Australia's crude rate of confirmed cases per 100,000 population was very high at 166.7; this compares to 74.1 in Chile, 72.8 in New Zealand, and 20.7 in Argentina. Australia also compares unfavourably to northern hemisphere countries on this measure; 21.6 in the UK, 21.1 in Mexico, and 12.5 in the USA. Australia compares more favourably in terms of hospitalisations per 100,000 population at 21.4. Similar rates were observed in New Zealand (22.7), and Argentina (22.1), but much lower rates in Chile (9.1), Canada (4.4), the USA (3), and the UK (2.7).[3] Of the number hospitalisations, 13% were in intensive care units (ICUs) and this was much higher than expected (Bishop 2009). Overall, the above measures indicate that with respect to other countries in 2009, Australia's H1N1 epidemic can be regarded as relatively severe.

In 2003 there was a near pandemic of SARS; analyses of this episode estimated very large temporary economic effects in highly affected regions, such as China and Hong Kong, among others (Chou et al. 2004; Hai et al. 2004; Lee and McKibbin 2004). It follows that we might expect that the 2009 H1N1 pandemic would also have large temporary economic effects on highly affected regions. Here we estimate what those effects might be for Australia with a focus on the macroeconomic adjustments that would take place in response to the epidemic. Thus, we take an economywide approach to estimating the economic impacts of an H1N1 pandemic. Beutels et al. (2008) argue convincingly that economic analysis of public health emergencies of international

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[1] To quote WHO (2010a), "The reported number of fatal cases is an under representation of the actual numbers as many deaths are never tested or recognized as influenza related."

[2] General Practitioners are the first point of contact for most Australians when they are seeking non-emergency medical care.

[3] These figures are as at September 2009.

concern (such as H1N1 influenza) should not take a partial equilibrium approach and focus on only the health sector (or parts of the health sector), while ignoring effects in other parts of the economy.[4] Illness due to public health emergencies raises perceptions of risk and leads to risk-modifying behaviour in an effort to reduce the risk of contracting the illness, e.g., prophylactic absenteeism from work and public gatherings. Both of these risk-modifying behaviours affect consumption and labour productivity, which in turn will affect all parts of the economy to a greater or lesser extent. An economywide approach is the ideal framework for evaluating the economic impacts of public health emergencies such as H1N1 influenza.

Our economywide analysis applies the MONASH-Health model of the Australian economy (Dixon et al. 2010a). MONASH-Health is a detailed, dynamic, computable general equilibrium (CGE) model of the Australian economy. The theoretical structure of MONASH-Health is similar to that of the MONASH model of Australia (Dixon and Rimmer 2002). MONASH-Health places special emphasis on the health sector to aid economic analysis of health sector issues. The health sector detail allows us to carefully target the increased demand on health services that an H1N1 epidemic would be expected to cause.

The MONASH-Health model is modified in a number of important ways to help capture the likely effects of a flu pandemic. Three separate tourism sectors are dissected from the model data: domestic, inbound and outbound. Previous experience with the SARS pandemic indicates that international tourism is strongly negatively affected by pandemics of this kind (Pine and McKercher 2004; Wilder-Smith 2006). This is one example of risk-modifying behaviour that is expected to reduce the risk of contracting the illness. Identifying international tourism separately in the model allows us to accurately target the assumed negative effects on international tourism of a flu pandemic.

In previous applications, the MONASH-Health model produced annual results (Brown et al. 2009). For this project, the model has been modified so that it produces quarterly results; quarterly behaviour is an uncommon characteristic of CGE models.[5] This modification is important because it is likely that an epidemic will have sharp effects over a short time period. An annual model tends to smooth out short-term effects leading to potential underestimation of disruption. For example, if an epidemic caused an 80% loss of inbound international tourism within a particular quarter, then the adjustment path of the tourism industry would be quite different from that in a situation in which international tourism declined by 20% for a year. Similarly, a 20% increase in a single quarter in demands for medical services related to infectious diseases would place more stress on the medical system than a 5% increase spread over a year.

MONASH-Health specifies capital accumulation separately for each industry. A typical feature of most CGE models (and many other neoclassical models) is the assumption that capital rental rates adjust in each industry so that capital is fully employed, i.e., full capacity utilisation. Here we allow for the real world feature of

[4] Smith et al. (2005) also argue against a health sector-focused approach in evaluating the economic impact of health care.

[5] The first quarterly CGE model of which we aware is Kydland and Prescott (1982). In an Australian context, the first example is Adams et al. (2001).

excess capacity, which we impose by following the modelling strategy of Dixon and Rimmer (2010). Their work shows that when it is assumed that capital rental rates adjust in each industry so that capital is fully used, it involves sharp reductions in rental rates on capital in response to reductions in demand; we would expect reductions in demand from a flu epidemic (e.g., tourism). Lower rental rates on capital lead to a net capital outflow and a real exchange rate depreciation (a reduction in the domestic price level relative to the price level in the rest of the world). Thus, an export upturn will be observed in the short-run. This is an unrealistic response to a demand-contracting shock: for example, this is not a feature of the current US recession. Such unrealistic export responses can be reduced by allowing for less-than-full capacity utilisation.

We also assume that real wages adjust asymmetrically in response to changes in labour market conditions (Dixon et al. 2009). Thus, we assume in policy simulations that the deviation in the real wage rate from its basecase forecast level increases at a rate that is proportional to the deviation in aggregate hours of employment from its basecase forecast level. The coefficient of proportionality is chosen so that the employment effects of a favourable shock to the economy are limited to a 2% deviation from basecase levels, beyond which benefits are realised entirely as real wage growth. For unfavourable shocks the coefficient ensures that most of the cost of unfavourable shocks are realised as negative deviations in employment from basecase levels rather than a fall in real wages.

Applying the modified model outlined above, we simulate the economic effects of two H1N1 epidemics in Australia; one being an estimate of the Australian 2009 outbreak and the other a significantly more severe episode infecting about 8 million Australians. There are a number of previous studies focussing on the economywide effects of global pandemics. Lee and McKibbin (2004) estimate the global economic impacts of the 2003 SARS outbreak by applying the G-Cubed model. They find the impact of SARS on the economies of China and Hong Kong is large, and that the impact depends on how consumer and investor expectations adjust to the disease. Chou et al. (2004) conduct a similar analysis to Lee and McKibbin (2004) applying the GTAP model. They also estimate large effects for China and Hong Kong, but also for Singapore, and smaller effects for Taiwan. Fan (2003) reports estimates of the economic impact of SARS generated using a quarterly macroeconomic model (the Oxford Economic Forecasting model). The analysis found that Hong Kong would be the most affected region, with smaller but still significant effects for China, Taiwan, Indonesia, Malaysia, Singapore and Thailand.

McKibbin and Sidorenko (2006) analyse the implications on the global economy of pandemic influenza outbreaks of varying severities. They apply the scenarios to the G-cubed model and find significant effects on global output even for a mild outbreak; there is a very uneven distribution of effects across regions. Jonung and Roeger (2006) estimate the macroeconomic effects on the EU economy of a European pandemic using a quarterly macroeconomic model of the EU25. Their results are in line with McKibbin and Sidorenko (2006) and suggest that while a pandemic would have significant economic effects they would not be severe. Keogh-Brown et al. (2009b) use a quarterly macroeconomic model of the UK (COMPACT) to analyse the economic impact of influenza pandemics. In general, they find the effects would be short and sharp, similar to the studies already mentioned. The work reported here is in same tradition as the above-mentioned studies.

2. The model

2.1 Overview

MONASH-Health is a detailed, dynamic, CGE model of the Australian economy (Dixon et al. 2010a); it places special emphasis on the health sector to facilitate economic analysis of health sector issues, e.g., MONASH-Health represents the health sector with 18 separate treatment activities (Table 1). In the application reported here, a version of the model in which there are 59 industries is applied. The detailed representation of the health sector in MONASH-Health represents a new development for CGE models. Previous work in this area usually treats the health sector by either subsuming it within a broader sector (e.g., Keogh-Brown et al. 2009a; Keogh-Brown et al. 2009b; McKibbin and Sidorenko 2006) or representing it as a single separate sector (e.g., Keogh-Brown and Smith 2008).

Table 1 Health treatment industries/commodities in MONASH-Health

1. Cardiovascular	10. Genitourinary
2. Nervous system	11. Endocrine, nutritional & metabolic
3. Musculoskeletal	12. Skin diseases
4. Injuries	13. Maternal conditions
5. Respiratory	14. Infectious and parasitic
6. Oral health	15. Diabetic mellitus
7. Mental disorders	16. Neonatal causes
8. Digestive system	17. Congenital anomalies
9. Neoplasms	18. Signs, symptoms, ill-defined conditions and other contact with the health system

The health treatment activities in MONASH-Health allow the user to carefully target changes in (i) demand for health services caused by epidemics or other health promotion activities, and (ii) supply of health services through changes in institutional arrangements and other health-sector reforms. Just as importantly, the health treatment activities are linked to other sectors of the economy via inter-industry demands and also the market for productive factors. Thus, the indirect effects of changes in demand or supply of the treatment industries can be captured simultaneously with the direct effects. These are the major benefits of using an economywide model with a health sector focus for analysing the economic impacts of health sector changes.

The non-health treatment sectors are treated in a fashion that is typical for detailed CGE models (see, for example, Francois and Reinert 1997). There is a representative firm for each sector that uses a CES (constant elasticity of substitution) combination of primary factors (agricultural land, labour and physical capital) and intermediate inputs (all non-health commodities). There is limited substitution between the primary factor composite and intermediate inputs, and also between individual primary factors; intermediate inputs are mostly used in fixed proportions. Firms' outputs can be sold to other firms, capital creators (for investment), the representative household, the government, or exported. All domestic agents can choose to buy domestically-produced or imported goods; this choice is also handled by a CES function. Ex-duty prices of imports are assumed to be fixed. Exports are assumed to respond to foreign currency prices, which are endogenous. Thus, the terms of trade are endogenous. Total household consumption is assumed to be a fixed proportion of household disposable income; total government consumption is assumed to be fixed.

MONASH-Health includes three types of dynamic mechanisms: capital accumulation; liability accumulation; and lagged adjustment processes. Capital accumulation is specified separately for each industry. An industry's capital stock at the start of year t+1 is its capital at the start of year t plus its investment during year t minus depreciation. Investment during year t is determined as a positive function of the expected rate of return on the industry's capital (see Dixon and Rimmer 2002, p.190, for further details).[6] Liability accumulation is specified for the public sector and for the foreign accounts. Public sector liability at the start of year t+1 is public sector liability at the start of year t plus the public sector deficit incurred during year t. Net foreign liabilities at the start of year t+1 are specified as net foreign liabilities at the start of year t plus the current account deficit in year t plus the effects of revaluations of assets and liabilities caused by changes in price levels and the exchange rate. Lagged adjustment processes are specified for the response of wage rates to gaps between the demand for and the supply of labour by occupation.[7]

In a MONASH-Health simulation of the effects of policy and other shocks, we need two runs of the model: a baseline or business-as-usual run and a policy run. The baseline is intended to be a plausible forecast[8] while the policy run generates deviations away from the baseline caused by the shocks under consideration (e.g., an outbreak of H1N1 influenza). For the non-health treatment sectors, the baseline incorporates trends in industry technologies, household preferences and trade and demographic variables. These trends are estimated largely on the basis of results from historical runs in which the MONASH model is forced to track a piece of history (see Dixon and Rimmer 2002, p.38, for further details). forecasts of demand for each treatment industry have been developed and applied through to 2023. For the health treatment sectors, the baseline incorporates forecasts that have been developed from Australian Institute of Health and Welfare data outlining expected future demand for each treatment. Most macroeconomic variables are exogenous in the baseline so that their paths can be set in accordance with forecasts made by expert macroeconomic forecasting groups such as the Australian Treasury and Access Economics. This requires endogenisation of various macroeconomic propensities, e.g.,

6 In this application expected rates of return are only a function of current period variables, i.e., capital creators are assumed to have adaptive expectations. We feel this is appropriate for the application analysed here; an H1N1 epidemic is an event rather than a policy change. Further, it is a new event of unknown magnitude at the time occurs. It is difficult to envisage how capital creators could accurately predict future variables affecting the rate of return given these characteristics of the epidemic.

7 This last dynamic mechanism gives MONASH-Health New Keynesian behaviour with respect to the labour market (see, for example, Mankiw and Romer 1991).

8 Thus, the model baseline is a non steady-state baseline.

the average propensity to consume. These propensities must be allowed to adjust in the baseline run to accommodate the exogenous paths for the macroeconomic variables.

The policy run in a MONASH-Health study is normally conducted with a different closure from that used in the baseline. In the policy run, macroeconomic variables must be endogenous: we want to know how they are affected by the shocks under consideration. Correspondingly, macroeconomic propensities are exogenised and given the values they had in the baseline. More generally, all exogenous variables in the policy run have the values they had in the baseline, either endogenously or exogenously, with the exception of the variables of interest. Comparison of results from the policy and baseline runs then gives the effects of moving the variables of interest away from their baseline values. For the present study, the baseline and policy runs differ with regard to the values given to exogenous variables representing an outbreak of H1N1 influenza. We interpret the differences between the results in the baseline and the policy runs as the effects of the outbreak.

2.2 A linear equation system

The model is represented by equations specifying behavioural and definitional relationships. There are *m* such relationships involving a total of *p* variables and these can be compactly written in matrix form as

$$A\boldsymbol{v} = \mathbf{0}\,, \tag{1}$$

where A is an $m \times p$ matrix of coefficients, $\boldsymbol{v}$ is a $p \times 1$ vector of *percentage* changes in model variables and $\mathbf{0}$ is the $p \times 1$ null vector. Of the *p* variables, *e* are exogenous (e.g., measures of the H1N1 pandemic). The *e* variables can be used to shock the model to simulate changes in the $(p-e)$ endogenous variables. Many of the functions underlying (1) are highly nonlinear. Writing the equation system like (1) allows us to avoid finding the explicit forms for the nonlinear functions and we can therefore write percentage changes (or changes) in the $(p-e)$ variables as linear functions of the percentage changes (or changes) in the *e* variables. To do this, we rearrange (1) as

$$A_n\boldsymbol{n} + A_x\boldsymbol{x} = \mathbf{0}, \tag{2}$$

where $\boldsymbol{n}$ and $\boldsymbol{x}$ are vectors of percentage changes in endogenous and exogenous variables. A_n and A_x are matrices formed by selecting columns of A corresponding to $\boldsymbol{n}$ and $\boldsymbol{x}$. If A_n is square and nonsingular, we can compute percentage changes in the endogenous variables as

$$\boldsymbol{n} = -A_n^{-1}A_x\boldsymbol{x}. \tag{3}$$

Computing solutions to an economic model using (3) and assuming the coefficients of the *A* matrices are constant, is the method pioneered by Johansen (1960).

Equations (1) represent the percentage-change forms of the nonlinear functions underlying the model; these forms are derived by total differentiation. Thus, (1) is an approximation based on marginal changes in the independent variables. So (3) only provides an approximate solution to the endogenous variables $\boldsymbol{n}$; for marginal changes in

x the approximation is accurate but for discrete changes in ***x*** the approximation will be inaccurate. The problem of accurately calculating ***n*** for large changes in ***x*** is equivalent to allowing the coefficients of the *A* matrices to be nonconstant. The problem is solved by breaking the change in ***x*** into *i* equal percentage changes. The multistep solution procedure requires that there are $(i-1)$ intermediate values of the underlying (levels) values of ***n***, i.e., ***N***. The intermediate values of ***N*** are obtained by successively updating the values of ***N*** after each of the *i* steps is applied. Once the values of ***N*** are updated for any given step, the coefficients of the ***A*** matrices in (3) are recomputed before (3) is solved again.[9]

2.3 Theoretical modifications

2.3.1 Tourism demands

To facilitate capturing the effects on tourism of a swine flu epidemic, we separate out three tourism sectors from the model data: these are domestic, international inbound and international outbound. The modifications to the model data are described in Dixon et al. (2010a); here we describe the changes made to the theory of the model to allow for the new sectors in the model.

MONASH-Health assumes households derive utility (U) from the consumption of *i* individual goods (X_i):

$$U = LES(X_i); \tag{4}$$

where the function *LES* represents the well-known linear expenditure system. We modify (4) by adding an extra good representing tourism expenditure (X_{i+1});

$$U = LES(X_i, X_{i+1}). \tag{5}$$

The LES makes demands for X_i and X_{i+1} a function of total consumption (C), the number of households (Q) and the prices of $X_i(P_i)$ and $X_{i+1}(P_{i+1})$.

There are three tourism goods in the model: domestic, international inbound and international outbound. International inbound tourism is consumed by foreigners and so does not enter the domestic household's utility function. Thus X_{i+1} only represents domestic $\left(X^d_{i+1}\right)$ and international outbound tourism $\left(X^i_{i+1}\right)$. These two tourism goods are somewhat substitutable. We handle this *a priori* behaviour by specifying

$$X^d_{i+1} = DDS\left(X_{i+1}, P_{i+1}, P^d_{i+1}, P^i_{i+1}\right). \tag{6}$$

Demand for X^i_{i+1} is a function of the same independent variables as those in (6). The function *DDS* in (6) represents Theil's (1980) differential approach to consumption theory. This makes X^d_{i+1} and X^i_{i+1} a function of X_{i+1} and their relative prices.

[9] The model is implemented and solved using the multistep algorithms available in the GEMPACK economic modelling software (Harrison and Pearson 1996).

2.3.2 Quarterly adjustment

MONASH-Health typically produces annual results (see, for example, Brown et al. 2009). But for the work presented here the model has been modified so that it produces quarterly results. This modification is important because it is likely that an influenza epidemic will have sharp effects over a short period. An annual model tends to smooth out effects leading to potential underestimation of disruption. This is the advantage of studies such as Fan (2003), Jonung and Roeger (2006) and Keogh-Brown et al. (2009), which use models with quarterly periodicity.

Modifying the model to produce quarterly results requires the adjustment of all stock-flow relationships and lagged adjustment mechanisms so that they reflect quarterly movements per model period rather than annual movements. As an example, capital in industry *j* normally accumulates according to:

$$K_j^{t+1} = K_j^t[1 - D_j] + I_j^t; \tag{7}$$

where K_j^t is the quantity of capital available for use in industry *j* during year t, I_j^t is the quantity of new capital created for industry *j* during year t, and D_j is the rate of depreciation, treated as a parameter. With I_j^t representing annual investment, K_j^{t+1} in (7) will accumulate capital at annual rate. To adjust the rate of capital accumulation to reflect a quarterly rate of accumulation with no change in the values of any variable in (7), we modify (7) to

$$K_j^{t+1} = K_j^t[1 - \frac{D_j}{4}] + \frac{I_j^t}{4}. \tag{8}$$

In equation (8), *t* now refers to a quarterly rather than annual time period; (8) now replaces (7) in the model. Other modifications to MONASH-Health to produce quarterly behaviour are documented in Dixon et al. (2010a).

2.3.3 Capital idling

In allowing for excess capacity, we follow Dixon and Rimmer (2010). The basic idea requires that capital rental rates be viewed as sluggishly adjusting mark-ups on variable costs (wage plus materials) that fall in response to excess capacity. Whereas the typical view of rental rates is that they represent market clearing prices for the use of existing capital stocks. We implement the former view in the policy run and this requires that we distinguish between capital in use $\left(KU_j^t\right)$ and capital in existence $\left(KE_j^t\right)$: excess capacity is where $KE_j^t > KU_j^t$. Thus, equation (8) in the previous section is rewritten in terms of KE_j in place of K_j.

We allow for sticky rental rates and excess capacity in the policy run only, via

$$\left\{\frac{Q_j^t}{Qb_j^t} - 1\right\} = \left\{\frac{Q_j^{t-1}}{Qb_j^{t-1}} - 1\right\} + \alpha\left\{\frac{KU_j^t}{KE_j^t} - 1\right\} + S_j^t,\ \forall t; \tag{9}$$

where Q_j^t and Qb_j^t are the rental rates for industry *j* in quarter *t* in policy and baseline simulations, S_j^t is a slack variable, and α is a positive parameter. S_j^t is used to implement (9) in the policy run only, and to turn off (9) once $KE_j^t = KU_j^t$. Note also that $Q_j^t = f\left(KU_j^t,...\right)$, $\forall t$, where *f* is a decreasing function.

In (9) the degree of rigidity in the rental price deviation $\left\{\frac{Q_j^t}{Qb_j^t} - 1\right\}$ is controlled by α, which is the rental price deviation elasticity of excess capacity per quarter. The elasticity is currently set at 0.05. This means that if we set all other terms to zero in (9), 10% excess capacity will cause a -0.5% rental price deviation from baseline. This gives rental prices a high degree of rigidity.

Two adjustments are also made to the investment function. First, expected rates of return on investment, $EROR_j^t$, will be lower under excess capacity than under full capacity utilisation by defining them as

$$EROR_j^t = \left\{\frac{KU_j^t}{KE_j^t}\right\} ROR_j^t - \left\{1 - \frac{KU_j^t}{KE_j^t}\right\} D_j, \ \forall t. \tag{10}$$

That is, $EROR_j^t$ will be a weighted average of the rate of return on capital , ROR_j^t, and the negative of the depreciation rate, where the weights are the share of capital in existence that is in use and the share not in use. So we are assuming that capital not in use earns no rental and deteriorates at the depreciation rate.

Second, demands for additional capacity in period *t* (when demand for capital exceeds supply during recovery) are partially met by recommissioning idle capital from period *t*–1 (see Dixon and Rimmer 2010 for further details]. The appropriate parameter values are set so that around 16.5% of idle capital is recommissioned per quarter to satisfy demands for additional capacity.

2.3.4 Asymmetric wage adjustment

In policy simulations, MONASH-Health typically assumes that the deviation in the real wage from the basecase level increases at a rate that is proportional to the deviation in aggregate hours of employment from its basecase level:

$$\left\{\frac{W^t}{Wb^t} - 1\right\} = \left\{\frac{W^{t-1}}{Wb^{t-1}} - 1\right\} + \beta\left\{\frac{L^t}{Lb^t} - 1\right\} + U^t, \ \forall t. \tag{11}$$

In (11), W^t and Wb^t are the real wage rates in quarter *t* in policy and baseline simulations, L^t and Lb^t are employment in quarter *t* in policy and baseline simulations, U^t is a slack variable set exogenously at zero, and β is a positive parameter.

The coefficient of proportionality, β, is chosen so that, after 5 years the employment effects of a shock to the economy are realised almost entirely as deviations in the real wage. For this study we modify the wage adjustment mechanism to

$$\left\{\frac{W^t}{Wb^t}-1\right\}=\left\{\frac{W^{t-1}}{Wb^{t-1}}-1\right\}+\left\{f(x)-1\right\}+U^t\ ,\ \forall t\ ; \qquad (12)$$

where $f(x)$ is a function that ensures that the employment effects of a favourable shock to the economy are limited to a limit of a 2% deviation from basecase levels, beyond which benefits are realised entirely as real wage growth. For unfavourable shocks the coefficient ensures that most of the cost of unfavourable shocks are realised as negative deviations in employment from basecase levels (see Dixon et al. 2009, p.3 for further details).

3. MONASH-Health simulations

A major epidemic, e.g., a serious outbreak of H1N1 influenza, could have significant consequences for the Australian economy. These could arise from several channels including:

(1) temporary reductions in inbound and outbound international tourism and business travel;

(2) a temporary upsurge in sick leave and widespread school closures requiring withdrawal of parents from the labour force;

(3) a large surge in demand for hospital and other medical services;

(4) some deaths with a related permanent reduction in the labour force; and

(5) temporary cessation of large public gatherings, e.g., sporting events.

We have developed two quantitative scenarios covering factors (2) to (4). The scenarios are both constructed from the classic Susceptible-Exposed-Infected-Removed (SEIR) model of infectious disease transmission (Kermack and McKendrick 1927); Anderson and May 1992) with allowance for unobserved (mild and non-presenting) transmission. The infection rate, driving the S to E transition, is proportional to the product of S and I and so the model is non-linear. Given an initial reproduction number (the number of secondary cases arising from a primary case) that is greater than 1, the model will naturally show an initial exponential increase in the proportion of the population that is infected, followed by a decline and return to steady state (I = 0). The initial reproduction number is tuned to provide the desired total number of infections over the course of the epidemic.

3.1 Scenario 1: the 2009 outbreak

The first scenario is based, wherever possible, on available data for the 2009 H1N1 outbreak as of November 2009 (DHA 2009). Unfortunately, this does not include data-based estimates for the total number of infections in the Australian population. Based on pandemics of the 20th century, observations from 2009 and scenarios used to inform the *Australian Health Management Plan for Pandemic Influenza* (DHA 2008), we assume that approximately 20% of the Australian population (4.3 million Australians)[10] are infected with H1N1 and experience symptoms over the second half of 2009, i.e., quarters 3 and 4. In this scenario we impose three sets of shocks. We assume:

(S1) that out of the 4.3 million people who experience symptoms: 3.9 million seek no medical attention but spend $5 (2009 dollars) on pharmaceuticals; 0.44 million seek medical attention (by visiting a general practitioner or a flu clinic) but are not hospitalised, incurring expenses of $61 (2009 dollars); 4,500 are hospitalised and survive, incurring expenses of $3,564 (2009 dollars); 857 are hospitalised and spend time in an ICU, incurring expenses of $12,356 (2009 dollars), of which 670 survive and 187 die.[11] The presentation venues for the 4.3 million symptomatic individuals have been chosen to reflect the official Australian presentation counts. Table 2 shows the assumed proportional split of ILI presentation to different venues. Altogether medical expenses are $73 million (2009 dollars) incurred over a six month period. This amounts to a 4.1% increase in demand for medical services relating to respiratory treatments over 2009.Q3 and 2009.Q4. We assume that demand for respiratory treatments returns to normal in 2010.Q1.

(S2) that workers miss a total of 3.2 million days of work over the two quarters 2009.Q3 and 2009.Q4 on account of their own sickness including 148,000 days while caring for children who are either sick or kept home by school closures. This assumes: 0.5 workdays per capita are lost by the 3.9 million who experience symptoms and seek no medical attention; 2.4 workdays per capita are lost by the 0.44 million who seek medical attention (by visiting a general practitioner or a flu clinic); 13.9 workdays per capita are lost by the 4,500 who are hospitalised and survive; and 0.5 workdays per capita are lost by 382,000 parents who have children 15 years of age or less and whose partner also works.[12] The total loss in workdays translates to a reduction in labour productivity of 0.48% (= 3.2 million days out of the 673 million days available from 11.2 million workers supplying 120 days each). We assume that labour productivity returns to normal in 2010.Q1.

(S3) that out of the 187 persons who die, 126 are workers. This translates into a permanent reduction in the labour force of 0.001%, phased in evenly over 2009.Q3 and 2009.Q4.

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[10] We include the following multiplicative factors to allow for the ILI presentation rate to differ from the true H1N1 rate: 5 for general practitioners and flu clinics, and 2 for non-ICU hospital admissions. These factors were chosen based on expert opinion and consultation with government during the early phases of the Australian outbreak (see Table 2).

[11] To be clear, the number of hospitalisations, ICU cases and deaths are based on actual data from DHA (2009).

[12] These per capita workday losses were suggested by Molinari et al. (2007) for working age people (18-64) in their study of seasonal influenza; the estimates take account of workforce participation rates.

Table 2 Key parameter values for the simulated epidemics in scenarios 1 and 2

Parameter	Scenario 1	Scenario 2	Comment
Percentage of population infected with H1N1 and displaying symptoms	20	30	Scenario 1: parameter values are based on estimates from historical (20th century) influenza pandemics, published pandemic preparedness modelling studies and expert opinion.
Percentage of H1N1 cases that are mild	95	75	
Percentage that are moderate	4	15	
Percentage that are severe	1	10	Scenario 2: parameter values are based on the assumption that the proportion infected with H1N1 is increased by 50% relative to scenario 1.
Non-presenting, GP, flu clinic split for mild cases (%)	99, 0.5, 0.5	99, 0.5, 0.5	
Non-presenting, GP, flu clinic split for moderate cases (%)	90, 5, 5	90, 5, 5	
Proportion of severe cases allocated to GP, flu clinic, hospital (non-ICU), ICU (%)	44, 43, 11.3, 1.7	32, 33, 30, 5	Scenario 1: splits to hospital and ICU set to reflect recorded presentations. Scenario 2: splits are skewed to reflect more hospitalisations.
Proportion of ICU admissions resulting in death	28	56 (a further 20% of hospitalised cases die)	Scenario 1: as given in the national data set. Scenario 2: 0.26% of the Australian population dies, a value consistent with the case-fatality-rate in the Western world during the 1918-19 influenza pandemic.
Total ILI cases per true H1N1 case at GP, flu clinic, hospital and ICU (multiplicative factor)	5, 5, 2, 1	5, 5, 2, 1	Based on early findings of a surge in ILI (non H1N1) presentations to these venues, presumably due heightened public awareness and concern.

We further assume that during the two peak quarters of infection and cost that inbound and outbound tourism are negatively affected. Here we follow previous estimates of the effects of SARS and the Iraq war on Australian tourism for 2003 by Dwyer et al. (2006). Given that these estimates are for both the effects of SARS and the Iraq war, we conservatively assume half the effects estimated by Dwyer et al. (2006). We thus impose the following shocks:

(S4) during the first peak quarter of infection (2009.Q3) that inbound and outbound tourism are negatively affected by 7.9%, and during the second peak quarter of infection (2009.Q4) that inbound and outbound tourism are negatively affected by 1.2%. Tourism numbers recover smoothly to their basecase levels over the next two quarters (2010.Q1–2010.Q2). We assume that Australians who cancel their outbound tourism save their holiday money. This imparts a small reduction

(0.33%) to the average propensity to consume over 2009.Q3–2009.Q4, which we assume is reversed gradually over the period 2010.Q1–2010.Q2.

While it is likely that the 2009 H1N1 outbreak did lead to temporary reductions in large public gatherings, we were unable to reliably quantify those effects for this study. Thus we impose no such effects as part of our 2009 scenario. Note also that part of the shocks for scenario 1, in terms of increased demand for medical services and absenteeism, are not that dissimilar to the expected shocks that would occur every year due to influenza and ILIs. So the true impact on demand for medical services and absenteeism may be somewhat less than we have predicted.

3.2 Scenario 2: a severe outbreak

The second scenario is based on a severe H1N1 outbreak assumed to occur during the same period as scenario 1, i.e., 2009.Q2–2009.Q3. The proportion infected with H1N1 is increased by 50% to 6 million, and accounting for non-H1N1 ILIs the total number of symptomatic infections is 8.1 million. We impose three sets of shocks. We assume:

(S1) that out of the 8.1 million people who experience symptoms: 5.2 million seek no medical attention but spend $5 (2009 dollars) on pharmaceuticals; 2.6 million seek medical attention (by visiting a general practitioner or a flu clinic) but are not hospitalised, incurring expenses of $61 (2009 dollars); 179,000 are hospitalised and 144,000 survive, incurring expenses of $3,564 (2009 dollars); 63,000 are hospitalised and spend time in an ICU, also incurring expenses of $12,356 (2009 dollars). Of all hospitalisations, including those in ICU, 52,000 die. See Table 2 for the proportional breakdown of presentations. Altogether medical expenses are $1.6 billion (2009 dollars) incurred over a six month period. This amounts to a 31% increase in demand for medical services relating to respiratory treatments over 2009.Q3 and 2009.Q4. We assume that demand for respiratory treatments returns to normal in 2010.Q1.

(S2) that workers miss a total of 11.5 million days of work over the two quarters 2009.Q3 and 2009.Q4 on account of their own sickness and a further 200,000 days while caring for children who are either sick or kept home by school closures. The total loss in workdays translates to a reduction in labour productivity of 1.7% (= 11.7 million days out of the 673 million days available from 11.2 million workers supplying 120 days each). We assume that labour productivity returns to normal in 2010.Q1.

(S3) that out of the 52,000 persons who die, 35,000 are workers. This translates into a permanent reduction in the labour force of 0.32%, phased in evenly over 2009.Q3 and 2009.Q4.

(S4) that inbound and outbound tourism fall by 65% in 2009.Q3, remain at this low level in 2009.Q4 and then recover smoothly to their basecase level over the next four quarters. In setting the shocks for inbound and outbound tourism, we considered the experience in Asia during the SARS epidemic of 2003. This episode suggests that regions suffering a widespread influenza infection can incur reductions in inbound and outbound tourism in the range 20%–70% during the peak infection period (Pine and McKercher 2004; Wilder-Smith 2006). For our hypothetical severe H1N1 epidemic, we adopt a number towards the upper end of this range (65%). We assume that Australians who cancel their outbound tourism save their holiday money. This imparts a reduction (2.38%) to the average propensity to consume in 2009.Q3 that we assume is reversed gradually over the period 2010.Q1–2010.Q3.

As in scenario 1, we were unable to reliably quantify any effects a severe H1N1 outbreak may have on large public gatherings. Thus we impose no such effects as part of this scenario either.

4. Results

4.1 Scenario 1

This section reports MONASH-Health results for the effects of the 2009 scenario described above.

4.1.1 Employment and GDP

Chart 1 shows the combined effects of the shocks on aggregate employment and GDP. The main effect occurs in 2009.Q4 when employment falls 0.8% below the baseline; the reduction in GDP is even larger (1.3%). The decline in GDP relative to employment mainly reflects the loss in labour productivity. On average through 2009, the epidemic reduces aggregate employment by 0.3% and GDP by 0.5%. Aggregate employment is a little higher in 2010 with the 2009 epidemic than it would have been without it and GDP is unchanged. Through 2011, Chart 1 shows average positive deviations for employment and GDP of 0.1 and 0.05%. As indicated in Chart 2, the epidemic-related reduction in employment in 2009 causes real wage rates to be lower than they otherwise would have been. This allows the Australian economy to arrive in 2010 with enhanced international competitiveness so that when tourism recovers and the other epidemic-related shocks disappear, employment and output move above their baseline values.[13]

Chart 3 indicates the relative importance of the different shocks in determining the overall employment effects. We see that H1N1 deaths have almost imperceptible effects on aggregate employment due to the small number of deaths. Increased expenditure on medical services and away from other items of household expenditure has slightly larger employment effects: employment is a little higher in the short run. The main reason is that the production of medical services is considerably more labour intensive than production of most other items of household expenditure. Extra medical expenditures in 2009 have a small negative effect on aggregate employment in 2010. This is a reflection of the wage mechanism mentioned earlier: extra employment in 2009

[13] The improvement in Australia's international competitiveness is likely to be tempered by a global H1N1 pandemic that affects Australia's trading partners and competitors, i.e., their real wage rates are also likely to move below baseline, which would make Australia's exports and domestically-produced goods less competitive than suggested by our analysis here. But it is difficult to account for these trading partner and competitor effects in a national model like the one we are applying here, so we ignore these effects in our analysis. We thank John Madden for making us aware of this issue.

associated with medical expenditures weakens the competitive advantage that the Australian economy experiences in 2010.

Chart 3 shows that the main drivers of lower employment are lost workdays and the fall in international tourism, with each effect contributing roughly equally to the overall employment loss of 0.8%.

4.1.2 Investment and capital

Chart 4 shows that the epidemic reduces investment: by 0.6% in 2009.Q3; by 2.5% in 2009.Q4; and by 2.9% in 2010.Q1. In 2009.Q3 investment falls below baseline because demand-contracting (tourism) and cost-increasing (labour productivity) shocks reduce the rental value of capital. This damps expected rates of return and thereby reduces investment. It is also true that in 2009.Q3 the epidemic causes excess capacity to appear in some industries, particularly those related to tourism and construction. Excess capacity in 2009.Q3 has a strongly negative effect on in investment in 2009.Q4. Weak investment in 2009.Q4 causes further excess capacity to appear, explaining weak investment in 2010.Q1. In 2010.Q1, much of the pick up in demand for capital associated with the recovery in labour productivity and the start of the recovery in tourism is satisfied by working down the excess capacity that appeared in 2009.Q3 and 2009.Q4. With excess capacity peaking in 2009.Q4, the investment decline peaks one quarter later in 2010.Q1 and by 2010.Q2 investment starts to move back towards baseline. This is because excess capacity in 2010.Q1 is declining as capital in existence adjusts down and capital in use adjusts up. By 2010.Q2, excess capacity is eliminated.

4.1.3 Expenditure components of GDP

Chart 5 shows epidemic-induced movements in the real expenditure components of GDP. Exports decline sharply in 2009.Q3 reflecting the 8% reduction in inbound tourism. Although inbound tourism does not fully recover until 2010.Q2, aggregate exports move back close to their baseline path by 2009.Q4. The recovery of exports is assisted by a real depreciation of the exchange rate[14] (see Chart 6, to be discussed shortly) associated with weak investment. Imports decline sharply in 2009.Q3 and 2009.Q4. This reflects the reduction in outbound tourism and the decline in GDP. Private consumption closely follows the path of real GDP. Public consumption is treated exogenously and assumed not to be affected by the epidemic.

As shown in Chart 6, the initial movement in the real exchange rate is positive. Then there is a significant real depreciation. Eventually the real exchange rate returns close to its baseline. These movements can be understood through the movements in net capital outflow: savings (S) minus investment (I). With a fixed average propensity to consume in the model, savings and consumption (C) move with income (Y). Initially, in 2009.Q3, Y and C fall by about 0.8%, and I falls by about 0.6%. Thus there is a small net capital inflow that leads to a small real appreciation. In 2009.Q4, C falls to 1.4% below baseline whereas I falls to 2.5% below baseline, thus giving a small net capital outflow

[14] The real exchange rate is measured by movements in the Australian price level compared with price levels in trading partners expressed in a common currency. Negative movements in the real exchange rate indicate improvements in the international competitiveness of the Australian economy.

that drives the real exchange rate downwards. In 2010.Q1 a large net capital outflow emerges as *C* and *Y* begins to recover whereas investment continues to collapse, leading to a significant real depreciation. From 2010.Q2 onwards, investment starts to recover and net capital outflow is slowly eliminated and the exchange rate begins to move back towards baseline.

4.2 Scenario 2

This section reports MONASH-Health results for the effects of the severe scenario described above. The explanation of results is very similar to that above for scenario 1, with main points of departure being the size of the effects.

4.2.1 Employment and GDP

Chart 7 shows the combined effects of the shocks on aggregate employment and GDP. As with scenario 1, the main effect occurs in 2009.Q4 when employment falls 5.5% below the baseline. The reduction in GDP is much larger, 7.3% in 2009.Q3. As observed in scenario 1, the decline in GDP relative to employment mainly reflects the loss in productivity from lost workdays. On average through 2009, the epidemic reduces aggregate employment by 2.2% and GDP by 2.9%. Aggregate employment is 0.8% lower in 2010 with a severe epidemic than it would have been without it and GDP is 1.2% lower. Through 2011, Chart 7 shows average positive deviations for employment and GDP of 0.1% and 0.6%. As indicated in Chart 8, the epidemic-related reduction in employment in 2009 causes real wage rates to be lower than they otherwise would have been. This allows the Australian economy to arrive in 2010 with enhanced international competitiveness so that when tourism recovers and the other epidemic-related shocks disappear, employment and output move above their baseline values.

Chart 9 indicates the relative importance of the different shocks in determining the overall employment effects. We see that H1N1 deaths have almost no effect on employment in the short run but have a small negative effect in the long run. Short-run results in MONASH-Health are mainly demand driven and the deaths have little effect on aggregate demand. In the longer run, employment is determined mainly by labour supply: demand for labour adjusts to changes in supply via wage movements. Beyond 2010, H1N1-related deaths in 2010 reduce employment by reducing labour supply.

Increased expenditure on medical services and away from other items of household expenditure has a positive effect on employment in the short run. As mentioned earlier, this is because the production of medical services is considerably more labour intensive than production of most other items of household expenditure. Extra medical expenditures in 2009 have a small negative effect on aggregate employment in 2010: extra employment in 2009 associated with medical expenditures weakens the competitive advantage that the Australian economy experiences in 2010.

Similar to scenario 1, chart 9 shows that the main drivers of lower employment are lost workdays (labour productivity) and the fall in international tourism, with each effect contributing 1.9% and 4.3% to the overall employment loss of 5.5%. The main difference relative to scenario 1 is that the tourism effects on employment are about four times those of the labour productivity effects.

4.2.2 Investment and capital

Chart 10 shows that the epidemic reduces investment: by 3.7% in 2009.Q3; by 15.3% in 2009.Q4; and by 19% in 2010.Q1. In 2009.Q3 investment falls below baseline because demand-contracting (tourism) and cost-increasing (labour productivity) shocks reduce the rental value of capital. This damps expected rates of return and thereby reduces investment. It is also true that in 2009.Q3 the epidemic causes excess capacity to appear in some industries, particularly those related to tourism and construction. Excess capacity in 2009.Q3 has a large negative effect on investment in 2009.Q4. Weak investment in 2009.Q4 causes further excess capacity to appear, explaining weak investment in 2010.Q1. In 2010.Q1, much of the pick up in demand for capital associated with the recovery in labour productivity and the start of the recovery in tourism is satisfied by working down the excess capacity that appeared in 2009.Q3 and 2009.Q4. By 2010.Q2 investment starts to move back towards the baseline. This is because excess capacity in 2010.Q1 is declining as capital in existence adjusts down and capital in use adjusts up. By 2010.Q3, excess capacity is eliminated.

4.2.3 Expenditure components of GDP

Chart 11 shows epidemic-induced movements in the real expenditure components of GDP. The pattern of results strongly follows that already discussed for scenario 1. Exports decline sharply in 2009.Q3 reflecting the 65% reduction in inbound tourism. Although inbound tourism does not fully recover until 2010.Q4, aggregate exports begin to move back towards their baseline path by 2009.Q4. The recovery of exports is assisted by the real depreciation of the exchange rate in 2009.Q4 and 2010.Q1 (Chart 12). The real depreciation peaks at 4.8% in 2010.Q1 and 2010.Q2. This is much greater than that observed in scenario 1, and this is due to the much stronger fall in investment in scenario 2 compared with scenario 1 (18.1% cf. -2.9%). Imports decline sharply in 2009.Q3 and 2009.Q4. This reflects the reduction in outbound tourism and the decline in GDP. Private consumption closely follows the path of real GDP.

As shown in Chart 12, the real exchange rate is steady in 2009.Q3. Then there is a small depreciation in 2009.Q4 and a large depreciation in 2010.Q1. Eventually the real exchange rate returns to slightly above its baseline. As before, these movements can be understood by movements in net capital flows. Initially, in 2009.Q3, Y falls by 4.2%, C (and therefore S) by about 5.8%, and I by about 3.7%. Thus, the net capital flows remain approximately steady. In 2009.Q4, I falls to 15.3% below baseline and C (and S) to 8.5% below baseline; thus a large net capital outflow emerges that drives the real exchange rate downwards in 2009.Q4. The exchange rate depreciates further in 2010.Q1 as C and S begin to recover but investment falls even further below baseline driving even larger capital flows abroad. Beyond 2010.Q2, the macroeconomic expenditure aggregates, and correspondingly the real exchange rate, return close to their basecase paths.

5. Concluding remarks

A quarterly CGE model has been applied to simulate the economic effects on the Australian economy of two H1N1 epidemics; one being the relatively mild 2009 outbreak and the other a more severe episode infecting about 8 million Australians. The use of a model with quarterly periodicity rather than the usual annual periodicity allows the analysis to capture the short-run nature of an epidemic. Such an event would have its economic effects concentrated over no more than one or two quarters.

The analysis demonstrates that an H1N1 epidemic could have significant macroeconomic effects. It is likely that it would reduce household demands for international travel and demands by international tourists for hotels, travel and other services within Australia. It is also likely that industries would face increased costs via absenteeism. Both the demand decreases and cost increases associated with an epidemic of the size assumed in this work could be expected to cause a sharp reduction in investment with resulting adverse effects on employment and GDP. The simulations show reductions in employment and GDP in the peak quarter of the assumed epidemic as: 0.8% and 1.3% for the 2009 epidemic; and 5.5% and 7.3% for a severe epidemic. The analysis also demonstrates that the sharp downturn in economic activity would be short-lived with employment and GDP returning to business-as-usual growth rates within two to four quarters, depending on the severity of the epidemic.

It should be noted that our analysis does not take into a number of responses that are difficult to quantify but are likely as the severity of the epidemic increases. These are: the reaching of capacity constraints for hospitals in general and ICUs in particular; the change in risk-modifying behaviour as deaths become a much larger proportion of population; and the ameliorating effects of policy responses such as vaccination, prophylactic anti-viral medications and their costs.

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Chart 1. Effects of scenario 1 on aggregate employment and GDP (percentage deviations from baseline)

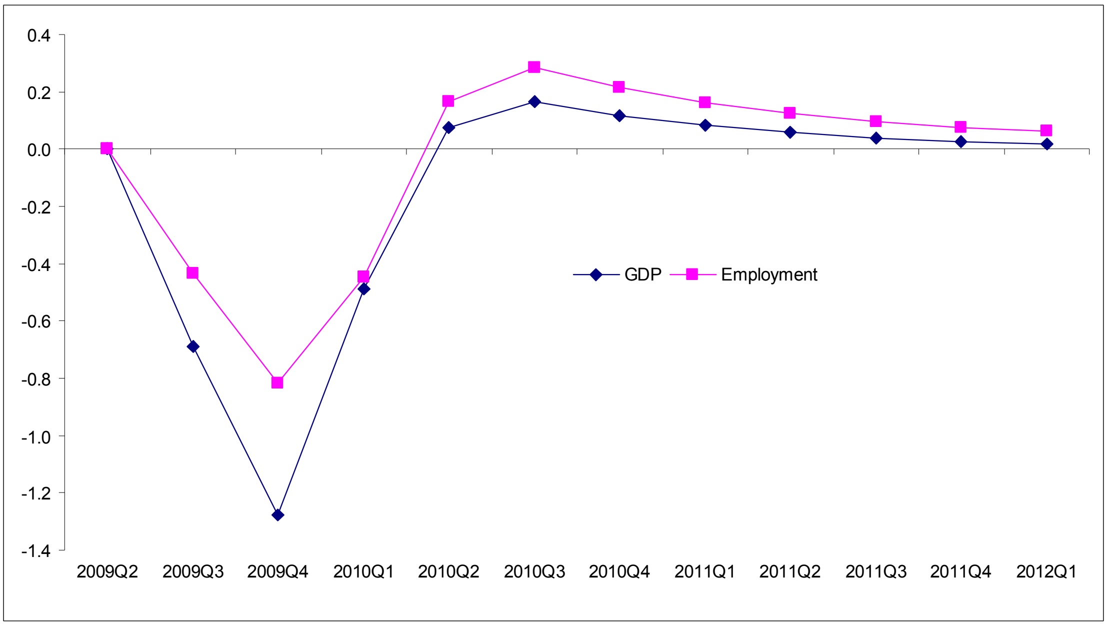

Chart 2. Effects of scenario 1 on aggregate employment and the real wage rate (percentage deviations from baseline)

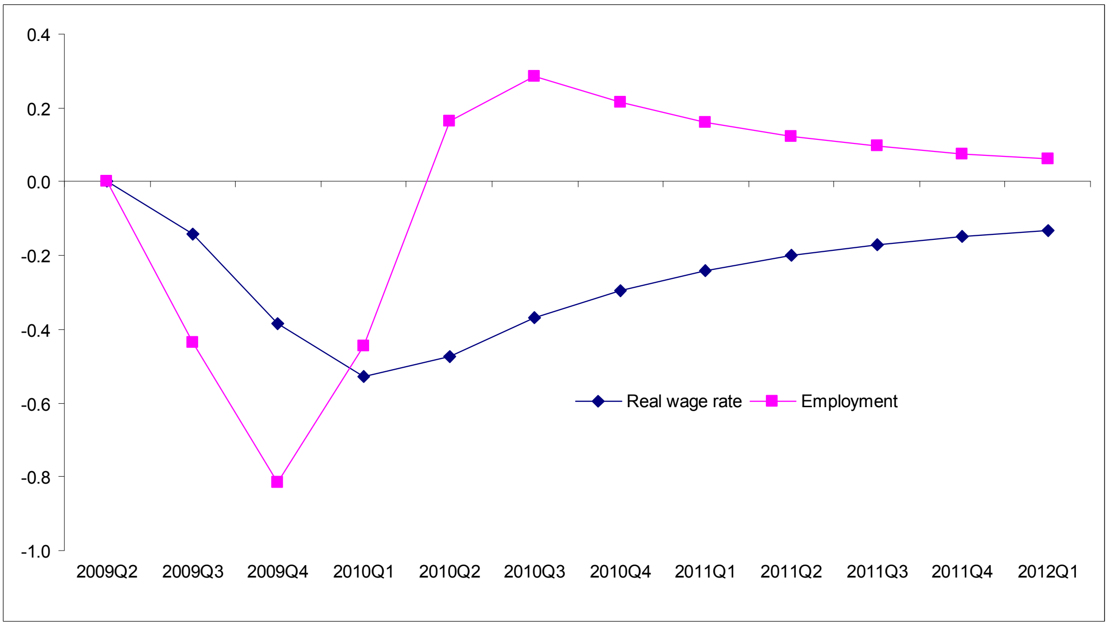

Chart 3. Effects of individual shocks of scenario 1 on aggregate employment (percentage deviations from baseline)

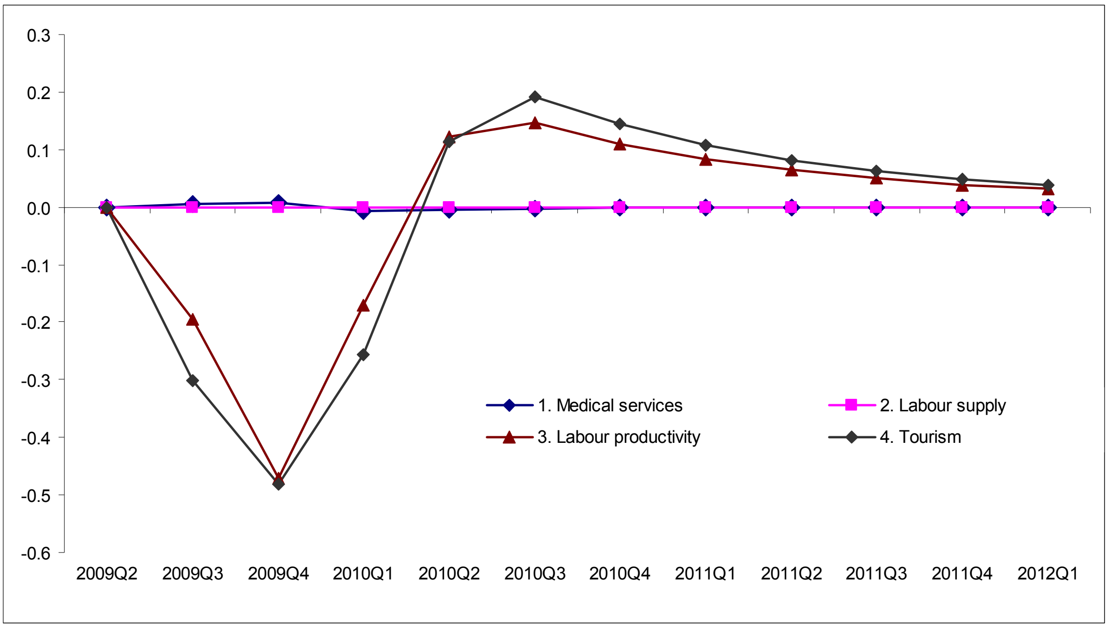

Chart 4. Effects of scenario 1 on aggregate investment and capital (percentage deviations from baseline)

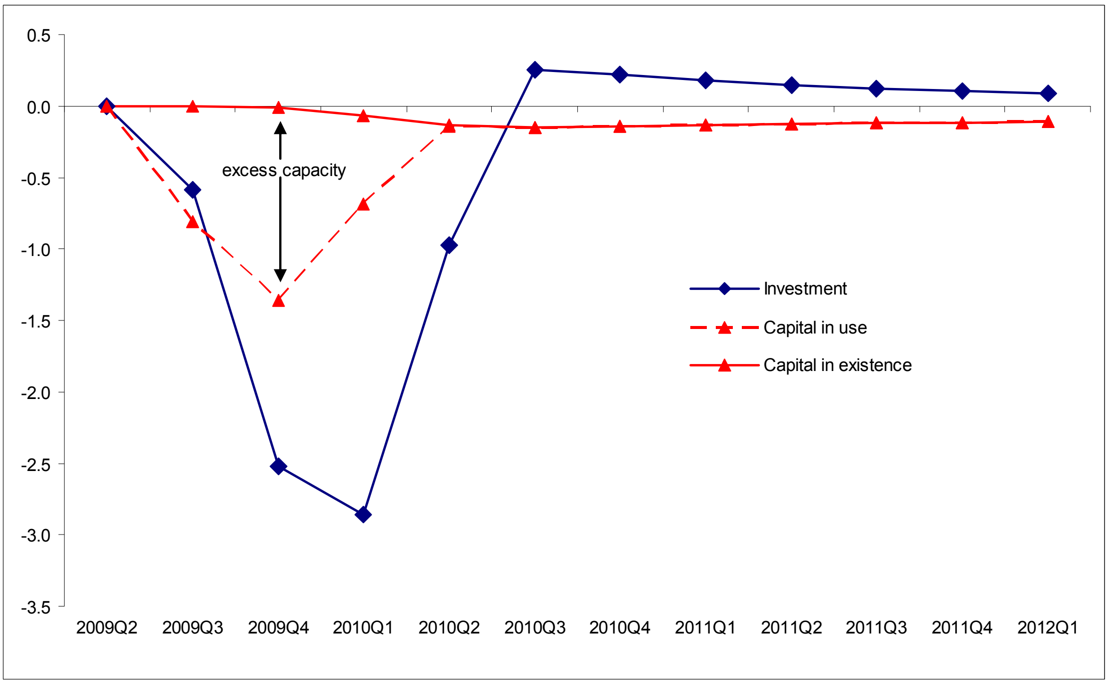

Chart 5. Effects of scenario 1 on expenditure components of GDP (percentage deviations from baseline)

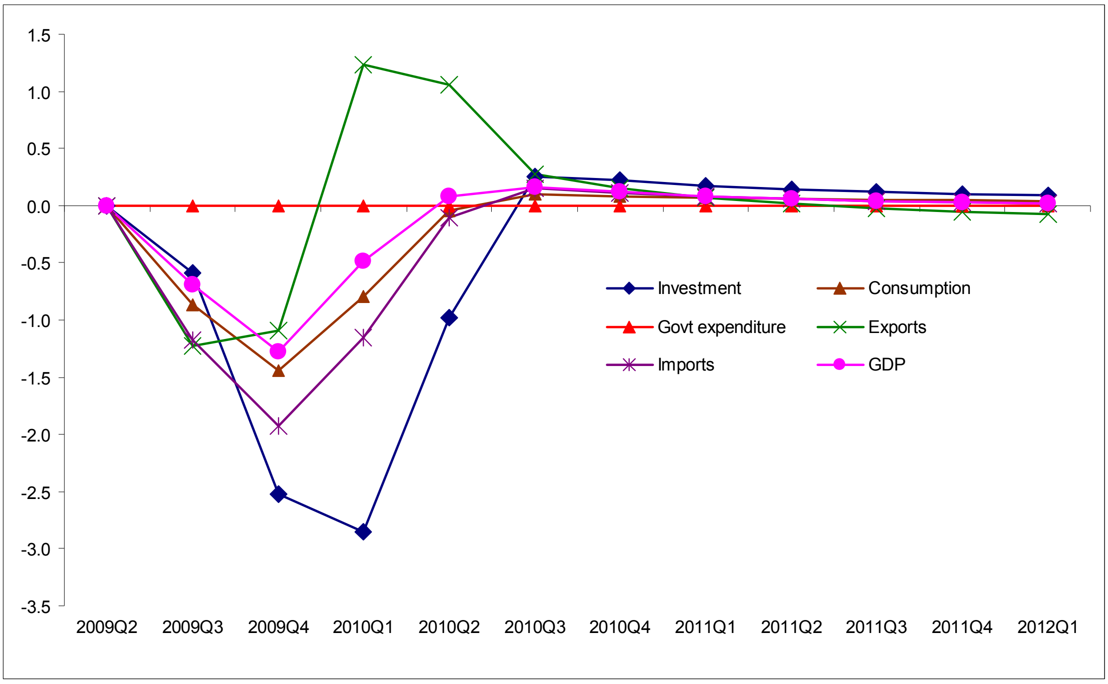

Chart 6. Effects of scenario 1 on the real exchange rate (percentage deviations from baseline)

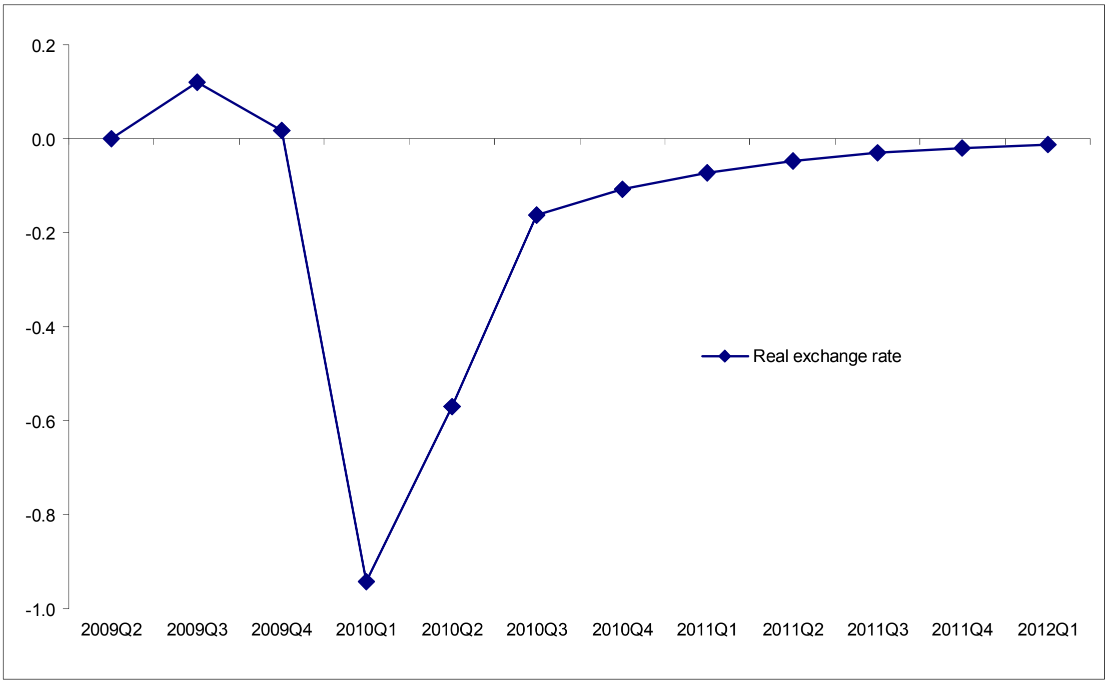

Chart 7. Effects of scenario 2 on aggregate employment and GDP (percentage deviations from baseline)

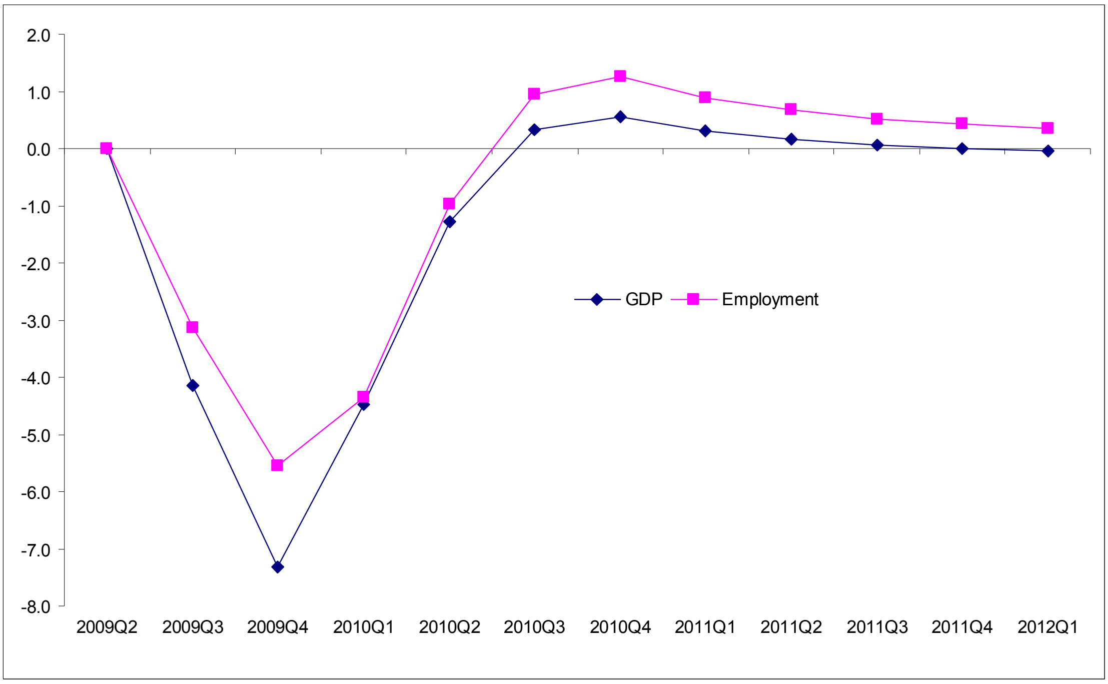

Chart 8. Effects of scenario 2 on aggregate employment and the real wage rate (percentage deviations from baseline)

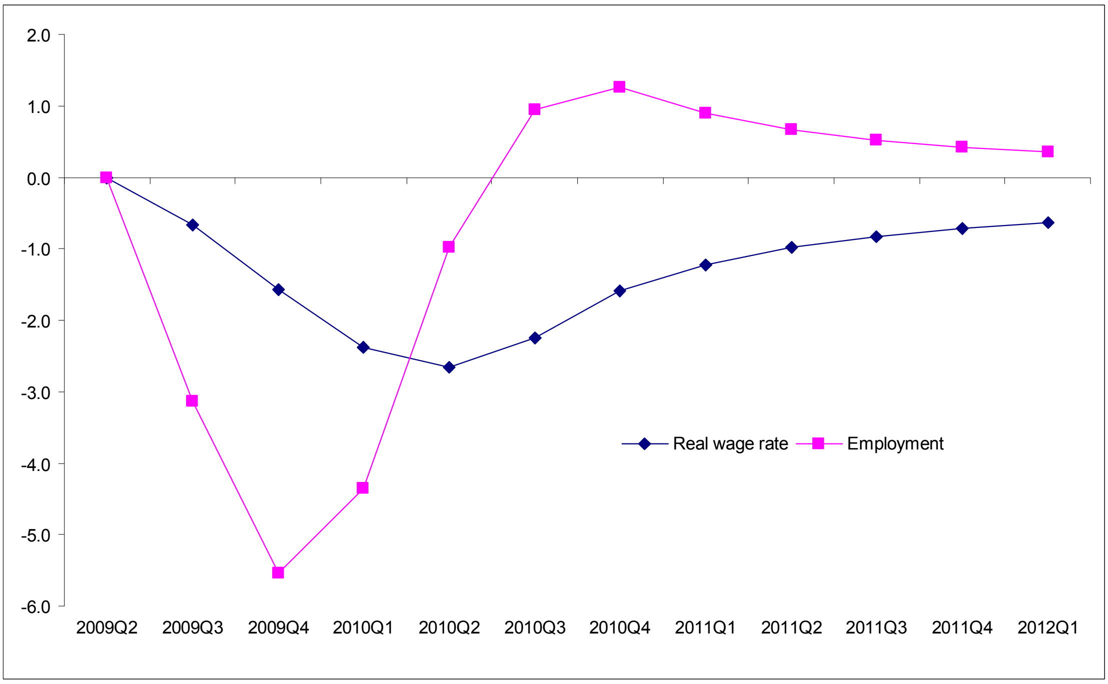

Chart 9. Effects of individual shocks of scenario 2 on aggregate employment (percentage deviations from baseline)

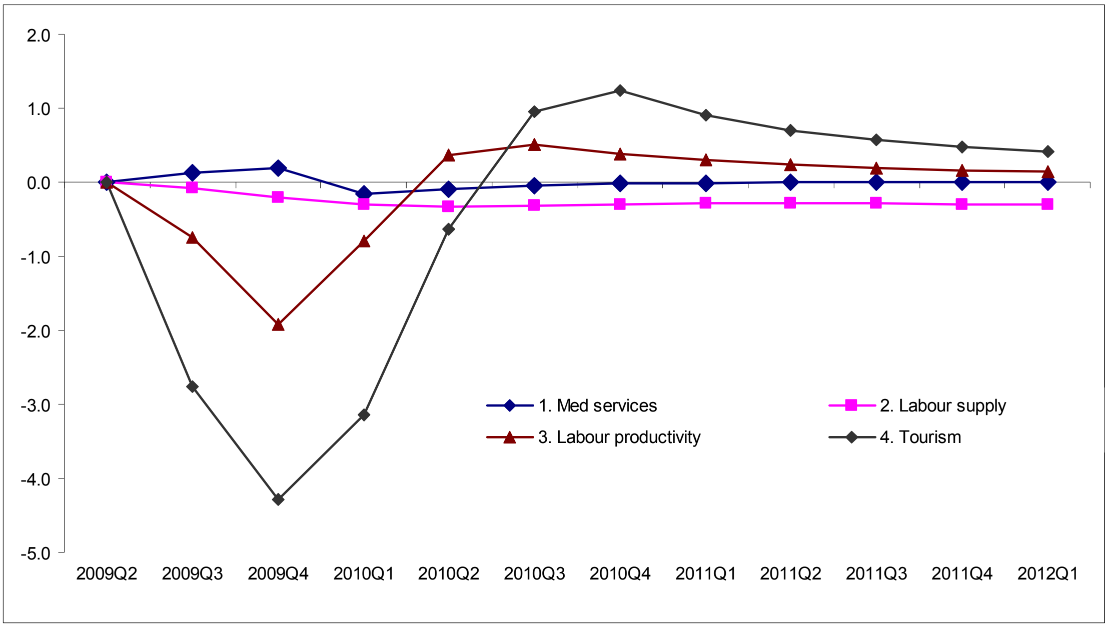

Chart 10. Effects of scenario 2 on aggregate investment and capital (percentage deviations from baseline)

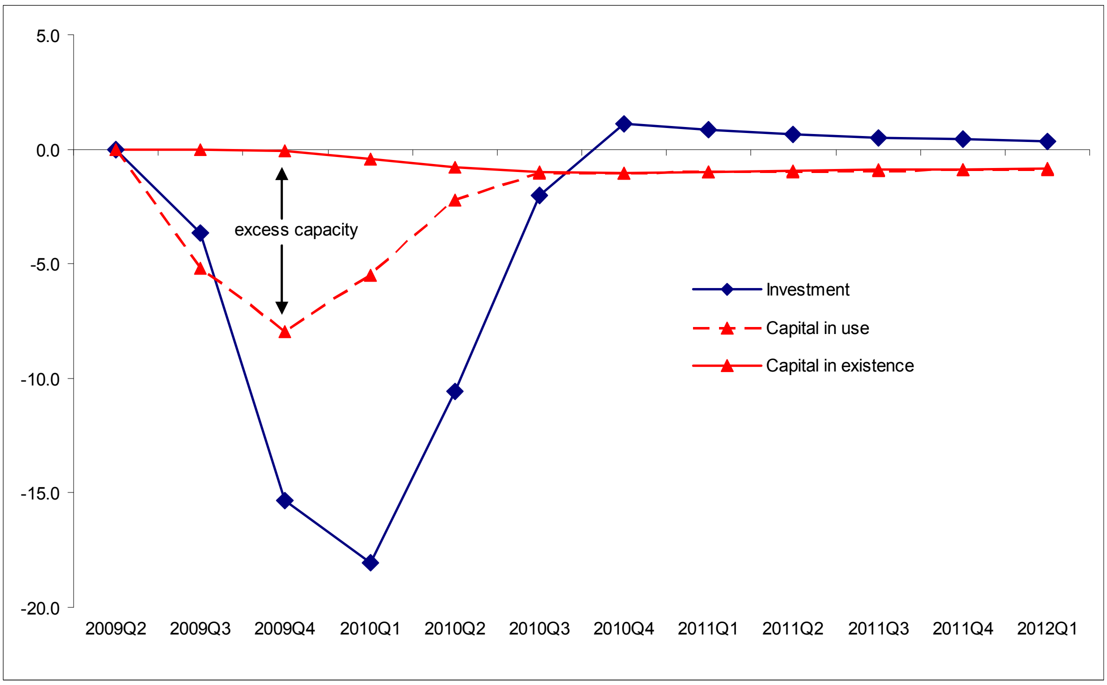

Chart 11. Effects of scenario 2 on expenditure components of GDP (percentage deviations from baseline)

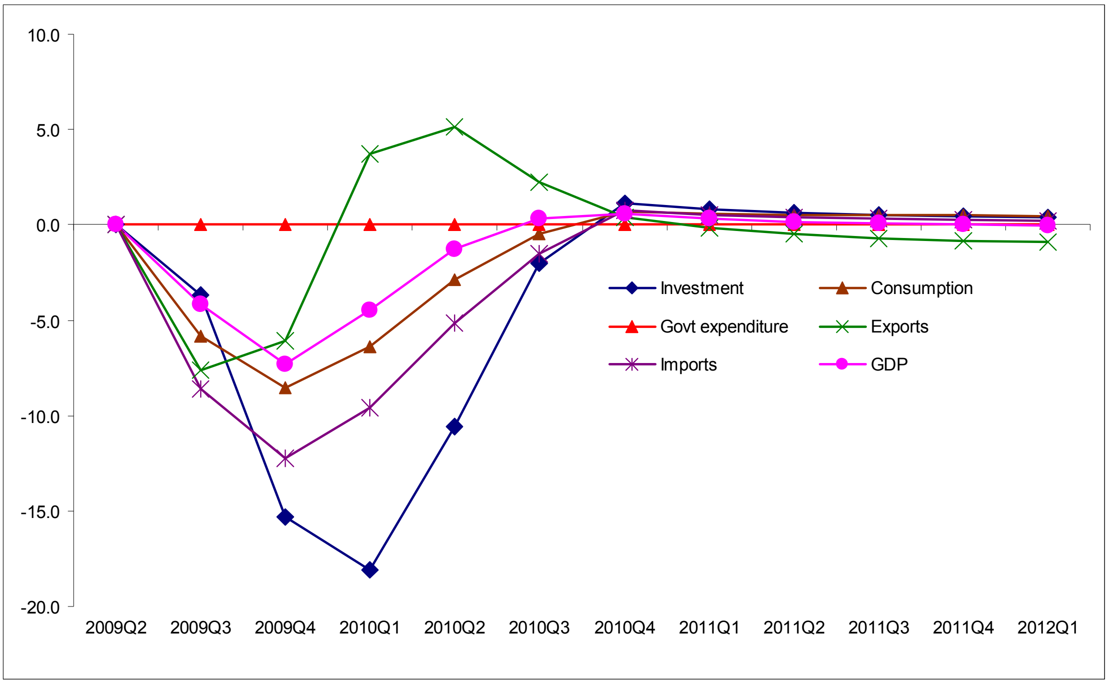

Chart 12. Effects of scenario 2 on the real exchange rate (percentage deviations from baseline)