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## Estimating the economic impact of pandemic influenza: An application of the computable general equilibrium model to the UK

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### ABSTRACT

There is concern regarding the impact that a global infectious disease pandemic might have, especially the economic impact in the current financial climate. However, preparedness planning concentrates more upon population health and maintaining a functioning health sector than on the wider economic impact. We developed a single country Computable General Equilibrium model to estimate the economic impact of pandemic influenza (PI) and associated policies. While the context for this development was the United Kingdom, there are lessons to be drawn for application of this methodology, as well as indicative results, to other contexts.

Disease scenarios were constructed from an epidemiological model which estimated case fatality rates (mild, moderate and severe) as 0.06%, 0.18% and 0.35%. A clinical attack rate of 35% was also used to produce influenza scenarios, together with preparedness policies, including antivirals and school closure, and the possible prophylactic absence of workers.

UK cost estimates (in Sterling) are presented, together with relative percentage impacts applicable to similar large economies. Percentage/cost estimates suggest PI would reduce GDP by 0.3% (£3.5bn), 0.4% (£5bn) and 0.6% (£7.4bn) respectively for the three disease scenarios. However, the impact of PI itself is smaller than disease mitigation policies: combining school closure with prophylactic absenteeism yields percentage/cost effects of 1.1% (£14.7bn), 1.3% (£16.3bn) and 1.4% (£18.5bn) respectively for the three scenarios. Sensitivity analysis shows little variability with changes in disease parameters but notable changes with variations in school closure and prophylactic absenteeism. The most severe sensitivity scenario results in a 2.9% (£37.4bn), 3.2% (£41.4bn) and 3.7% (£47.5bn) loss to GDP respectively for the three scenarios.

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### Introduction

The recent H1N1 ('swine flu') pandemic has heightened public, professional and policy concern regarding a global infectious disease pandemic. That this pandemic was mild does not preclude a more serious pandemic in the future. In fact, many aspects of the recent swine flu pandemic meant that it was, in some senses, *ideal* in that it began in the Americas rather than the developing world, leading to early detection, low pathogenesis, a reasonably high level of immunity in the adult population and sustained susceptibility to antivirals. Had these criteria not been fulfilled, as might be the case in a future pandemic, the consequences could have been much more serious.

In the last century there were three influenza pandemics – 1918, 1957 and 1968/69. The outbreak of Severe Acute Respiratory Syndrome (SARS) especially gave impetus to pandemic preparedness planning and conjecture regarding the anticipated pandemic and its impact (Keogh-Brown & Smith, 2008). However, preparedness planning generally concentrates upon the impact on population health and on policies to maintain a functioning health sector during a pandemic, although the wider economic impact of infectious disease pandemics, and policies to address them, has been the subject of increasing investigation (Keogh-Brown & Smith, 2008; Keogh-Brown, Wren-Lewis, Edmunds, Beutels, & Smith, 2010; McKibbin & Sidorenko, 2006).

The impact of the recent financial crisis has highlighted the importance of the financial sector to the global economy, playing an important part in many of the world's large economies. For example, the US is said to have the largest and most sophisticated financial services sector in the world (Nolan, Shippey, Woznick, &

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Hinkelman, 1995), financial services contributed approximately 8% of Australian GDP in 2003<sup>1</sup>, and 26.8% of GDP for Hong Kong in 2009,<sup>2</sup> The UK economy, which is used in this application to illustrate the potential impacts to ‘similar’ economies has a financial sector contributing 8% to total GDP<sup>3</sup> With respect to pandemic preparedness, this raises a specific policy question concerning the extent to which this sector may be affected by a pandemic, and the likely policies to mitigate the pandemic’s effects. The limited work thus far on the wider macroeconomic impact of pandemic influenza, alluded to above, has considered different aspects of an influenza pandemic but, in each case, the financial sector has been aggregated together with other service industries and sectors. As a result, little can be said about the sectoral impact of a pandemic over the results for the aggregated economic effect. The work presented here therefore focuses on assessing the macroeconomic impact of an influenza pandemic on a single country economy using a Computable General Equilibrium (CGE) model, which allows for a disaggregated finance sector, as outlined in the sector listing in the [Appendix](#), to generate greater specificity in analysis. Application of this model to multiple countries is possible, as the model specification would not differ if applied to different countries with large financial sectors. Although the underlying database would differ between countries, as would some model parameters such as elasticities, the results should be seen as reasonably comparable across “similar” countries. We therefore present the results from a model of the UK, but suggest that these results are indicative for other nations also.

The structure of this paper is as follows. In the next section we outline the sectors, input data, model and scenarios used for our modelling application. The results are then presented, discussed and conclusions drawn in the subsequent sections.

## Methods

### CGE model and data

CGE modelling is an established economic analysis tool, particularly since the development of the Social Accounting Matrix (SAM) approach to national accounting, e.g., (Pyatt, 1992; Stone, 1962a; Stone, 1962b), and the SAM approach to modelling, e.g., (Drud, Grais, & Pyatt, 1986; Pyatt, 1987). However, applications by health economists have been rare (Bell & Gersbach, 2009; Jonung & Roeger, 2006; Rutten & Reed, 2009; Smith, Keogh-Brown, Barnett and Tait, 2009; Smith, Yago, Millar, & Coast, 2005, 2006) and hence CGE remains novel in this field (Beutels, Edmunds et al. 2007; Smith 2008).

The model used in this paper is based on that used previously by the authors (Keogh-Brown, Smith Edmunds, Beutels et al., 2010). This is a single country CGE open-economy model consisting of 11 sectors. In the current paper this model has 12 sectors as the financial sector has been disaggregated to reflect elements of financial services, as defined below. The resultant 12 sectors (elaborated in the [Appendix](#)) are:

1. Agriculture, mining and food processing (Ag. mine & food proc)
2. Food (Food)
3. Manufacturing- materials (Manu materials)
4. Manufacturing- wood and paper products (Manu wood & paper prods)

5. Manufacturing – chemicals (Manu chem)
6. Manufacturing- machinery, electrical and luxury items (Manu-mach, elec & lux)
7. Utilities and construction (Utils & cons)
8. Retail hotels and restaurant (Retail, hotels & rest)
9. Transport and telecommunications (Trans & telecoms)
10. Banking, Investment and Insurance (Banking, Inv & Ins)
11. Other Business Services (Oth Bus Servs)
12. Other Services (Oth Servs)

Although the model is a single-country model, it is an open-economy model, meaning that foreign trade is captured through import and export functions. The differences between origins are encapsulated as follows. Domestically produced commodities are sold both in the domestic market and abroad. Sales abroad take the form of exports and are modelled using a Constant Elasticity of Transformation function. Domestic sales originate from domestic and foreign sources (imports) and this is modelled using a composite commodity and Armington assumption which determines the combination of domestically produced commodities and imports by means of a constant elasticity of substitution. Composite commodities can then be used as an input into the production process of the domestically produced commodities or sold for final consumption by households, government or investment. This is a common CGE model methodology and is used and outlined elsewhere (Löfgren, Harris, & Robinson, 2001; Smith, et al., 2005).

There are also differences with regard to the pricing of commodities. In the model the domestic price of commodities, the import price (cost insurance freight) in the currency of the world market, and the export price (free on board) are all parameterised. In order to enable prices to be transformed into currency on the world or domestic market an exchange rate is also parameterised in the model.

### Data

The core data concern prices, elasticities and the social accounting matrix (SAM). The sources for the SAM data are the UK 2003 supply and use tables, and Europa government statistics. The elasticities are taken from other research (Arndt, Robinson, & Tarp, 2002; Dimaranan, McDougall, & Hertel, 2006). Prices are calculated endogenously and the Harberger convention is used so that prices equal one in the benchmark equilibrium.

### Epidemiological scenarios

Scenarios are based on previous influenza pandemics in 1918, 1957 and 1968/69. In the UK (and many other countries), there were three distinct waves of the 1918 pandemic, each lasting 10–15 weeks (Ministry of Health, 1920) with the largest occurring in the autumn of 1918. In the autumn of 1957 a single wave pandemic occurred of about 15 weeks duration (Ministry Of Health, 1960). In 1968/69 a two-wave pandemic affected the UK resulting in a small first wave in March 1969, and a main wave in midwinter of 1969/70 (Cooper, Pitman, Edmunds, & Gay, 2006). Based on information from these previous pandemics, time series simulations were conducted to represent influenza mortality by age and over time for three different severities of pandemic (Kramer, 2007); these severities are referred to as mild (CFR = 0.06%), moderate (CFR = 0.18%) and severe (CFR = 0.35%). Note that the scenarios include allowance for a limited stock of antivirals to be made available to key workers, as this is part of the UK preparedness response; the impact of wider use of antivirals for the general public is considered in the sensitivity analysis.

<sup>1</sup> <http://www.bankers.asn.au/Default.aspx?ArticleID=618> (accessed 01/04/11).

<sup>2</sup> [http://www.gov.hk/en/about/aboutthk/factsheets/docs/service\\_economy.pdf](http://www.gov.hk/en/about/aboutthk/factsheets/docs/service_economy.pdf) (accessed 01/04/11).

<sup>3</sup> Oxford Economics 2006.

**Table 1**  
Disease and policy scenarios.

	Disease only Scenarios			Disease plus school closure Scenarios			Disease plus prophylactic absenteeism Scenarios			Disease, school closure and prophylactic absenteeism Scenarios		
	Mild	Moderate	Severe	Mild	Moderate	Severe	Mild	Moderate	Severe	Mild	Moderate	Severe
Severity of disease (years)												
Clinical Attack Rate % (Working Population)	35	35	35	32.9	32.9	32.9	35	35	35	32.9	32.9	32.9
Working Population Mortality rate %	0.020	0.063	0.128	0.020	0.063	0.128	0.020	0.063	0.128	0.020	0.063	0.128
Working Days Lost due to illness	5	7	10	5	7	10	5	7	10	5	7	10
% impact of illness absenteeism	0.795	1.114	1.591	0.749	1.048	1.497	0.795	1.114	1.591	0.749	1.048	1.497
School Closure (weeks)	0	0	0	3	3	3	0	0	0	3	3	3
% impact of school closure	0	0	0	0.593	0.593	0.593	0	0	0	0.593	0.593	0.593
Prophylactic Absenteeism (weeks)	0	0	0	0	0	0	3	3	3	3	3	3
% impact of PA	0	0	0	0	0	0	2.318	2.318	2.318	2.063	2.063	2.063
% Impact for year	0.816	1.177	1.719	1.362	1.704	2.218	3.134	3.495	4.037	3.424	3.767	4.281

*Parameterising the impact of pandemic influenza in the CGE model*

Pandemic influenza is incorporated into the model through the impact on the labour force (the working population) as a result of deaths and absenteeism. Deaths cause the permanent removal of workers from the labour supply for the year for which the pandemic is modelled. These were implemented by increasing the mortality rate of the working population.

By using epidemiological simulations possible patterns of infection, intervention and mortality for a specific set of lethality and  $R_0$  values can be examined (where  $R_0$  represents the expected number of secondary infections arising from a single individual during his or her entire infectious period). Because the precise nature of any future influenza pandemic is unknown, understanding the risk is best achieved by creating a representative set of plausible events. Here an ‘event set’ approach was used, consisting of a number of randomly generated simulations of the level of excess mortality (Kramer, 2007). Each of the events comprised within the set is defined by variables that are generated using distributions that reflect historical evidence. These variables include, for example, the ability of a virus to spread ( $R_0$ ), the likelihood that an infected person will die (lethality), and the probability that antivirals will to some degree be effective in reducing the impact of a new virus. Simulations then allow the probability that any particular severity is exceeded to be established. This allows mortality severities per pandemic influenza event to be related to the annual likelihood of such an event.

In the model, antivirals, stockpiled by many governments, are expected to slow the spread of influenza and substantially reduce overall illness and mortality by relieving symptoms and reducing infectivity. Limited economic modelling (Balicer, Huerta et al., 2005) suggests that pre-pandemic stockpiling of antiviral drugs can be cost-saving and that it would be cost-beneficial and cost effective to adopt strategies for their use in treating patients and possibly for short-term post exposure prophylaxis of close contacts of people who are infected. However, their effectiveness against a wide range of potential viruses is not fully understood. Antivirals were found to be reasonably effective in the recent swine flu pandemic, but their efficacy for future strains is unknown. The model therefore assumes that antivirals would not work at all – whether used for treatment or prophylaxis – in one in four simulated pandemics. Antiviral treatment is assumed to reduce infectiousness, as well as sickness and mortality. It will therefore slow the spread of the simulated pandemic and reduce death rates. Every person receiving antivirals is assumed to get them within 48 h of becoming sick. However, because this requirement is likely to be challenging even for the best of healthcare systems, it is assumed to be achieved in only 65% of people who become ill.

Absenteeism causes a temporary absence from work and these absences are calculated as fractions of the working year; assumed to be 220 days. Pandemic influenza plans (DoH, 2007; DoH & HPIH&SD, 2005) suggest that absence from work for infected individuals will vary from 5 to 10 days. The most severe pandemics (those with highest fatality) are assumed to result in a longer

**Table 2**  
Sensitivity analysis scenarios AV and CAR.

	School Closure and Prophylactic Absenteeism Scenarios (Sensitivity Base)									Low CAR			High CAR		
	Base			Limited AV			Unlimited AV			Base			Base		
	Mild	Moderate	Severe	Mild	Moderate	Severe	Mild	Moderate	Severe	Mild	Moderate	Severe	Mild	Moderate	Severe
Severity of disease (years)															
Clinical Attack Rate % (Working Population)	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.9	23.5	23.5	23.5	47.1	47.1	47.1
Working Population Mortality rate %	0.020	0.063	0.128	0.026	0.084	0.142	0.015	0.053	0.112	0.020	0.063	0.128	0.020	0.063	0.128
Working Days Lost due to illness	5	7	10	5	7	10	5	7	10	5	7	10	5	7	10
% impact of illness absenteeism	0.749	1.048	1.497	0.749	1.048	1.497	0.749	1.048	1.497	0.535	0.749	1.070	1.070	1.497	2.139
School Closure (weeks)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
% impact of school closure	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593
Prophylactic Absenteeism (weeks)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
% impact of PA	2.063	2.063	2.063	2.063	2.063	2.063	2.063	2.063	2.063	2.063	2.063	2.063	2.063	2.063	2.063
% Impact for year	3.424	3.767	4.281	3.430	3.787	4.295	3.419	3.757	4.265	3.210	3.467	3.853	3.745	4.216	4.923

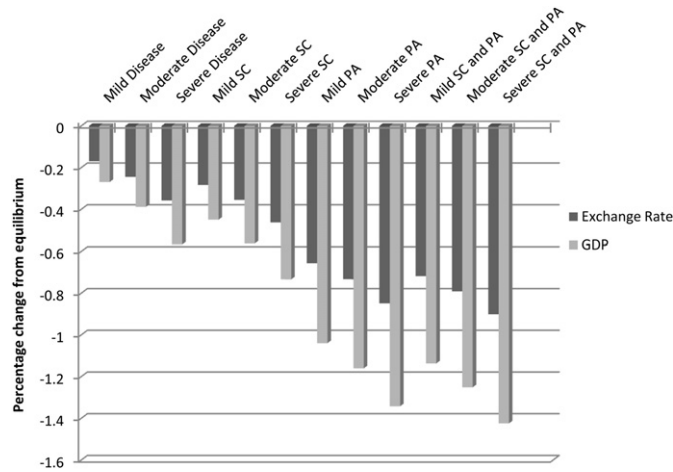


Fig. 1. Impact on GDP and exchange rate.

duration of illness for those that survive. Based on the severity of the pandemics, the mild scenario will result in 5 days of absence from work for infected individuals whilst the moderate scenario will result in 7 days of absence and the severe scenario will result in 10 days of absence. As suggested (DoH, 2007; DoH & HPIH&SD, 2005; HPA, 2006), a 35% clinical attack rate for each pandemic is assumed, i.e. 35% of the population would be infected. These scenarios, together with their impact on the working population, are shown in Table 1. The clinical attack rate for pandemic influenza is unknown, so scenarios were run as tabulated in Table 2 with a 25% and 50% clinical attack rate (CAR) to allow for variability (the CARs referred to are slightly mitigated by school closures in some scenarios and the specifics of this mitigation are outlined later).

School closure

In addition to the ‘pure’ disease scenarios outlined above, school closures may be implemented to reduce the otherwise rapid spread of disease amongst school children. Table 1 outlines the impact of a three -week school closure policy as outlined in (Ferguson et al., 2006). We assume that this school closure will mitigate the pandemic in the proportion described in (Ferguson et al., 2006) where a 34% CAR was estimated to reduce by 2% due to school closure. Analysis of the Labour Force Survey (2005) suggests that there are a total of 25,245,000 individuals aged 16–64 who are in paid employment in the UK. Of these 3,900,000 are women who are

Table 3  
Welfare measures.

Disease Scenario	Welfare (%)	Example UK Monetary Value (£bn)
Mild Base Disease Only	0.20	2.55
Moderate Base Disease Only	0.28	3.69
Severe Base Disease Only	0.42	5.41
Mild School Closure	0.33	4.28
Moderate School Closure	0.41	5.36
Severe School Closure	0.54	7.00
Mild Prophylactic Absenteeism	0.77	9.95
Moderate Prophylactic Absenteeism	0.86	11.12
Severe Prophylactic Absenteeism	0.99	12.88
Mild School Closure & Prophylactic Absenteeism	0.84	10.88
Moderate School Closure & Prophylactic Absenteeism	0.92	12.00
Severe School Closure & Prophylactic Absenteeism	1.05	13.68

Domestic Output To Home Market

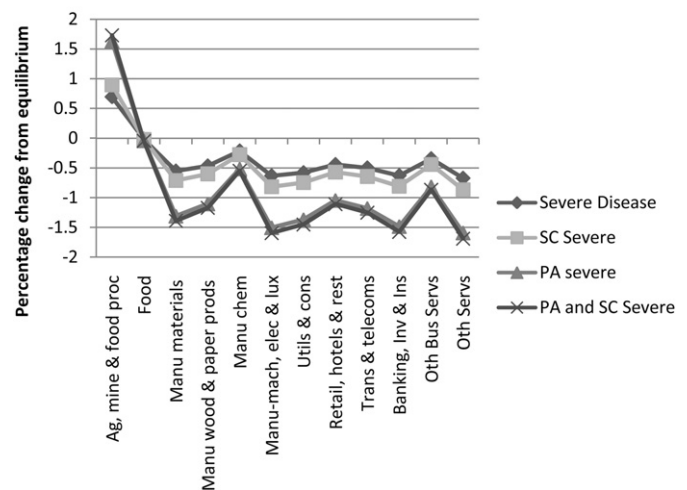


Fig. 2. Domestic output by sector.

either the head of the household or the spouse of, or cohabiting with, the head of the household and have dependent children in the household aged under 16 years. That is, 15.5% of the workforce comprises women who are probably responsible for dependent children (Sadique et al., 2007). However, other research suggests that 54% of parents have access to informal care arrangements for their children (Sadique, Adams, and Edmunds, 2008) and we use this estimate to mitigate the absences resulting from school closure.

Prophylactic absenteeism by workers

A further possibility is prophylactic absenteeism, where healthy workers remove themselves from their workplace in an attempt to avoid infection. Such absenteeism is likely to be limited in its duration. (DoH, 2007) suggests that most worker absence will occur during a 2–3 week period and it may be reasonably assumed that this is the time period that is most likely to provoke prophylactic absence and worker fear. It also agrees with the assumed

Household Consumption

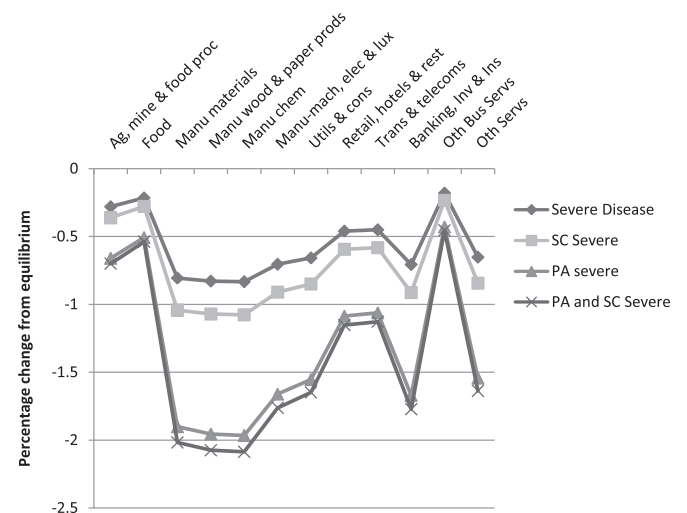


Fig. 3. Household consumption by sector.

# Exports

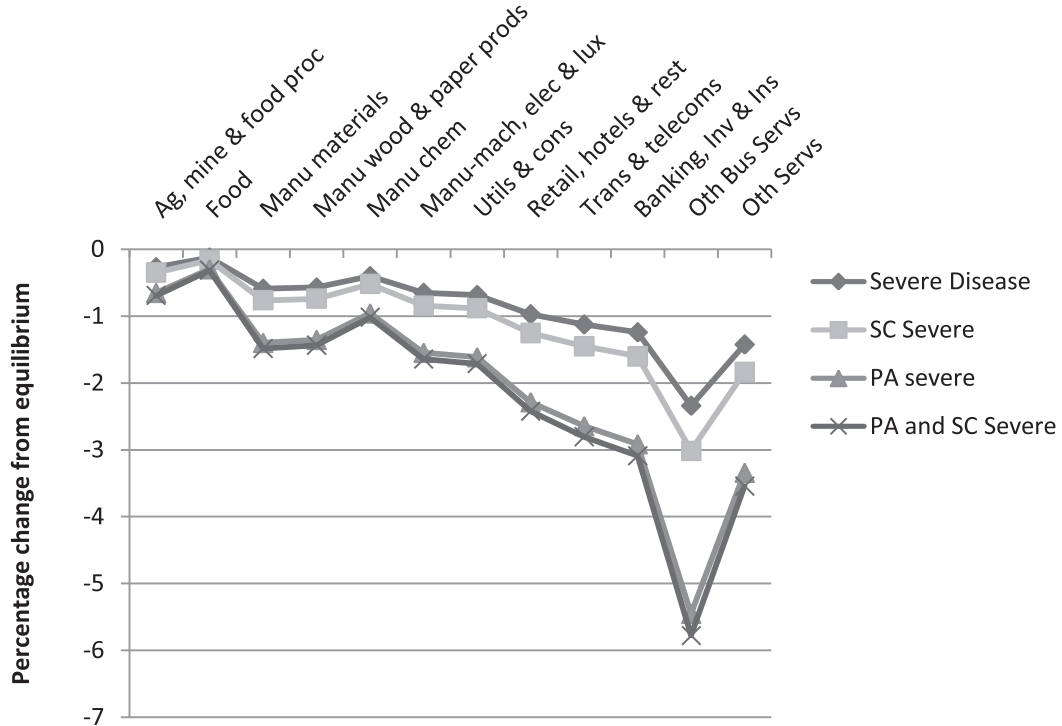


Fig. 4. Exports by sector.

duration of school closures and is therefore used as our estimate of prophylactic absence duration.

Amongst other issues, prophylactic absenteeism in the event of a major pandemic was surveyed in (Sadique et al., 2007). The results of this survey state that 34% of workers would take prophylactic absenteeism in the event of an influenza pandemic, of which 3.75% were women who had children at school and would therefore overlap with the school closure absenteeism. However, the remaining 30.25% represent the additional shock due to

prophylactic absenteeism. It should be highlighted that there is some uncertainty as to whether individuals who state a willingness to take prophylactic absenteeism would, in reality, carry out this intention, so this shock should be seen as a 'best guess' estimate which may be higher or lower in reality. Evidence to suggest a mitigation effect of school closure has already been outlined, but such mitigation is not assumed in response to prophylactic absence. (Ferguson, et al., 2006) suggests that transmission rates in the workplace are similar to those in the home. A very small (1%)

# Imports

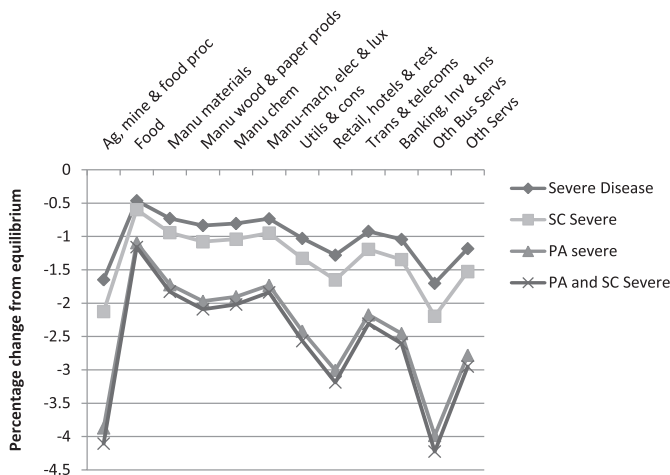


Fig. 5. Imports by sector.

# Investment Consumption

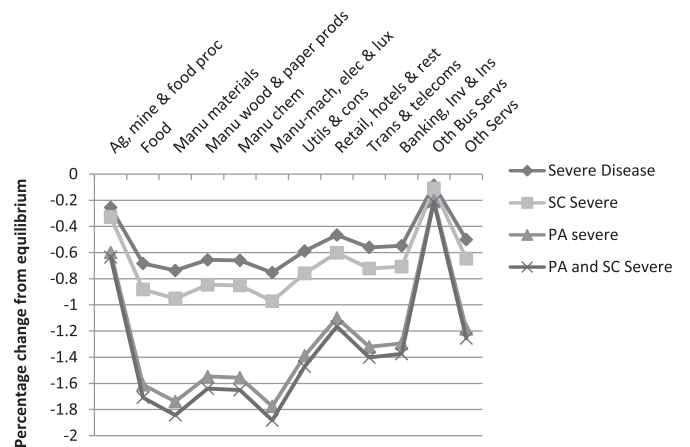


Fig. 6. Investment consumption by sector.

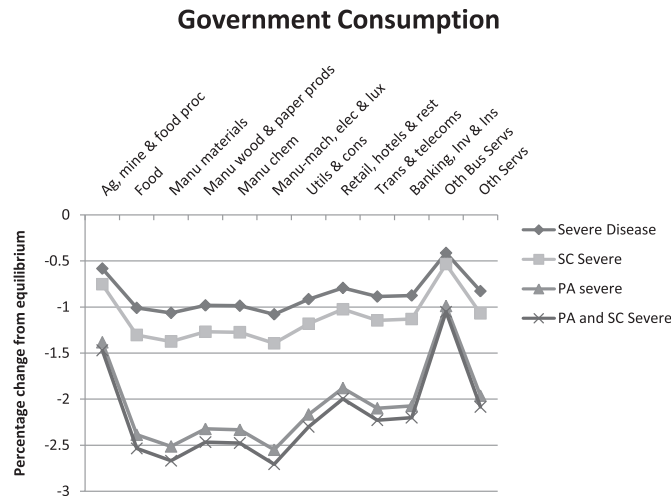


Fig. 7. Government consumption by sector.

mitigation effect for workplace closure is mentioned but this occurs when entire workplaces are closed, not for partial closure as might result from prophylactic absence. These scenarios are tabulated in Table 1.

The school closure and prophylactic absenteeism scenarios are considered in combination also and these are tabulated in Table 1.

## Results

The headline results concern the impact on the exchange rate and GDP for each scenario tabulated in Table 1. The percentage impacts on these parameters compared with the input equilibrium parameters are plotted in Fig. 1. The magnitude of effect for exchange rate is approximately 75% of the GDP impact for all scenarios, so comments focus here on GDP.

The GDP impact for disease only ranges from a reduction of approximately 0.26% for the mild scenario to approximately 0.56% for the severe scenario. These relative values would be broadly comparable to other countries or, converting these percentage losses to financial values, costs applicable to our UK example can be obtained. Losses in GDP due to the pandemic alone are £3.5bn, £5bn, £7.4bn for the three scenarios respectively (based on overall UK GDP of £1.3trn for 2007). Introducing four weeks of school closure would increase these losses to 0.45%, 0.56% and 0.73% respectively, equivalent to £58bn, £7.3bn and £9.5bn.

Introducing prophylactic absenteeism, rather than school closure, produces a more varied pattern of impact, since as well as having an increased disease effect, the duration of prophylactic absence was assumed to increase with the severity of disease. The GDP reductions for these scenarios were 1.03%, 1.16% and 1.34% for the mild, moderate and severe disease scenarios (equivalent to losses of £13.5bn, £15.1bn and £17.4bn respectively for the UK).

Finally, combining disease, school closures and prophylactic absenteeism yields, rather unsurprisingly, the largest impact, with reductions of 1.14%, 1.25% and 1.42% respectively, equivalent to UK losses of £14.8bn, £16.3bn and £18.5bn.

CGE modelling also produces the welfare measure of Equivalent Variation (EV), which represents the amount of money that, if an economic change does not happen, leaves the individual just as well off as if the change had occurred. This may be thought of as the amount of money that the individual might be willing to pay to avert the change. For the purposes of this paper, the welfare measure (EV) is quoted as a percentage of GDP, with the results presented in Table 3. These results follow a similar pattern to the

GDP and exchange rate effects and range from 0.2% for the mild disease only scenario up to 1.05%, suggesting that UK consumers overall would be willing to pay some £2.55bn to £13.68bn to avert the pandemic's economic impact. These estimates do not include individuals' willingness to pay to avoid the illness and possible death that accompany pandemic influenza.

## Sectoral impacts

Figs. 2–7 illustrate the impacts on the various sectors within the model. Note that the pattern of losses/gains across sectors is similar for all disease scenarios so discussion focuses on the severe disease ('worst case scenario'). All results represent a comparison with the benchmark equilibrium.

Agriculture, mining and food-processing sector, and food production sectors, are least affected. Domestic output to the domestic market increases in these sectors (Fig. 2) and losses to other indicators is small, with the exception of imports (Fig. 3) where there is a significant decline, suggesting that foreign sources of such goods are forgone in favour of using those produced domestically. However, since these sectors are essential for the supply of food, and perhaps the sectors where 'social mixing' is the least, it is reasonable to expect that it should exhibit smaller losses than other sectors.

The manufacturing industries and utilities and construction suffer large reductions in domestic output, large losses from household consumption (Fig. 4), investment consumption (Fig. 5) and government consumption (Fig. 6). Imports to these sectors are more affected than exports, suggesting that domestic consumption is transferred from imported to domestic output, which seems intuitive. Interestingly, together with the retail, hotels and restaurant sector (RHR) and transport and telecommunications sector (T\_T), these sectors also experience the greatest differential in impact between the situation concerning disease only, versus those with school closure, prophylactic absenteeism or all combined. This may reflect the more essential physical presence of workers in the manufacturing process, or the service sector, than elsewhere and less scope for capital substitution or virtual working (e.g. within financial sector). In terms of consumption (Figs. 3, 6 and 7) it is clear that absenteeism (due to school closure and/or prophylactically) generates a more severe impact than the disease itself.

Turning to the financial sector more specifically, there are significant variations in impact between business, investment and insurance (BII) and other business services sectors in consumption (Figs. 3, 6 and 7) and imports and exports (Figs. 4 and 5). Specifically, compared with BII, OBS generates smaller losses to household consumption, investment and government consumption, but large

Table 4  
Inflation and Employment.

	% Change in the economy-wide value of employed labour	Inflation
Disease Only Mild	-0.60	-0.28
Disease Only Moderate	-0.86	-0.41
Disease Only Severe	-1.26	-0.60
PA Mild	-1.00	-0.47
PA Moderate	-1.25	-0.59
PA Severe	-1.62	-0.77
SC Mild	-2.30	-1.09
SC Moderate	-2.56	-1.22
SC Severe	-2.96	-1.41
SC & PA Mild	-2.51	-1.20
SC & PA Moderate	-2.76	-1.32
SC & PA Severe	-3.14	-1.50





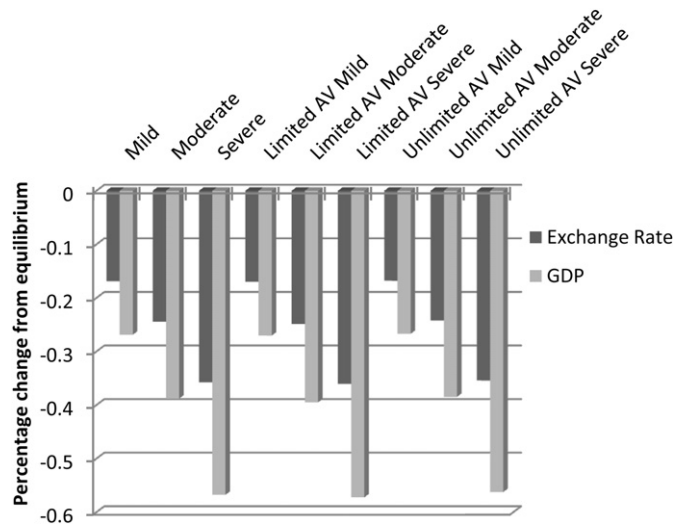


Fig. 8. Sensitivity to targeted antiviral prophylaxis.

effect means that the impact is at best negligible from a macro-economic perspective, especially when compared with the impact of prophylactic absenteeism and school closure.

As Fig. 9 demonstrates, the variation in clinical attack rate produces very little change in effect – approximately 0.2% or 0.3% of GDP. This result does not suggest that the clinical attack rate of the disease is unimportant, rather that the policies used to mitigate the disease effect are much more influential and appear to dwarf the disease effect. The variation of the number of working days lost through absence also has some effect on the overall impact but, like the clinical attack rate, it is a disease effect that is not as significant as the policy effects.

Despite large variations in school closure in our sensitivity analysis the model effects are most sensitive to prophylactic absence – the upper limit impact is 250% of the lower limit: the upper/lower limits for the mild, moderate and severe scenarios are 0.7%/1.8%, 0.8%/1.9%, and 1%/2.1% respectively. The mitigation effect of school closure, combined with its influence on a smaller proportion of the population than prophylactic absence, mean that it has a smaller impact than prophylactic absence. However, the change from lower to upper limits of school closure increases the GDP impact by more than 50%.

The results of the most severe sensitivity scenario, which incorporates upper limits of CAR, working days lost due to illness, school closure and prophylactic absenteeism are shown in Fig. 10. These results show a 2.9%, 3.2% and 3.7% loss to GDP for the mild, moderate and severe scenarios. Applying these rates to the UK example is equivalent to losses of £37.4bn, £41.4bn and £47.5bn respectively. These are the upper limits of the estimated effects from the model.

Finally, to allow for variation of the infectiousness of the pandemic disease, scenarios in Table 1 were also run with a 25% lower and 50% upper limit on the clinical attack rate. These values are tabulated in Table 7. For the disease only scenarios the impacts of the upper limit are approximately double those of the lower clinical attack rate, but the relative impact of the disease lessens with the introduction of mitigation policies.

## Discussion

The estimates provided in this paper indicate the likely magnitude of impacts on the economy of a wealthy nation with

a large financial sector in the event of an influenza pandemic, together with the impact of possible use of antivirals, school closure and workers taking prophylactic absenteeism.

Overall results indicate that the disease itself is not necessarily the greatest concern from a macroeconomic perspective. Although an influenza pandemic would reduce GDP by between 0.3% and 0.6% (equivalent to UK losses of £3.5–7.4bn), combining school closure and prophylactic absenteeism yields effects of 1.14–1.42% (£14.8–£18.5bn). It is therefore important to consider the epidemiological impact of school closure and prophylactic absenteeism and to attempt to strike a balance between policies affecting these and durations of absence that are necessary from a public health perspective without imposing unnecessary economic impacts. This raises a particular problem for Governments which must steer a difficult path between advice to “carry on as usual” and “social distancing” measures which may slow down the rate at which an epidemic grows.

There will be variation between sectors in terms of economic impact. In the case of the United Kingdom, of course, the financial sector is a very significant contributor to GDP, balance of payments and employment. In countries less dependent upon the financial sector, those sectors that are ‘essential’ (e.g. agriculture, mining, food production), are likely to be less affected than those that concern luxury items and services, such as most manufacturing, retail and real estate, that can be deferred until after the pandemic. With respect to the financial sector, whilst the impacts are certainly no more significant than on other sectors, it is at least equivalent, if not worse, in all respects compared with retail, hotels and restaurants, and transport and telecommunications, which elsewhere have been identified as those sectors likely to be worst hit by an infectious disease pandemic (Keogh-Brown & Smith, 2008; Lee & McKibben, 2004). Further, the rapidity of the impact that will strike the financial sector may influence the overall effect and is an area that requires further consideration in future developments of the model which, at present, takes an annual average rather than accounting for the transitional effects of the time period and duration of the outbreak. For instance, the shock in a small location such as financial heart of a country may last only 6–8 weeks, compared with 15 weeks for the country overall (DoH, 2007). In this case, absenteeism, for instance, from illness would result in a reduction in labour supply that is much more acute, but shorter lived, than currently estimated based on the yearly average.

Certainly there are limitations to the analysis presented here, principally centered on the availability of information on certain key parameters. Thus, the results should be viewed as providing an indication of the relative magnitude of effects for different scenarios rather than necessarily precise estimates of the economic impact, although these impacts may be broadly indicative for many countries of similar economic constitution to the UK.

In terms of the limitations, the impact of worker absence introduced by school closures and prophylactic absenteeism has been assessed but, since there is no feedback loop for the epidemiology of these policies, the impact of this absence has been estimated *without* accounting for the reduction in disease effect that these actions might produce. This is in agreement with the study by Ferguson, but there is a shortage of evidence to inform these assumptions and it is therefore quite possible that the economic impact due to this may be overemphasised. Parameter estimates of the school closure and prophylactic absence were also required but, in reality, the precautionary behaviour that will be used is quite unpredictable. Nonetheless, the sensitivity analysis goes some way towards illustrating the changes in effect that are yielded by these variations in behaviour and results were quite sensitive to the large variations in prophylactic

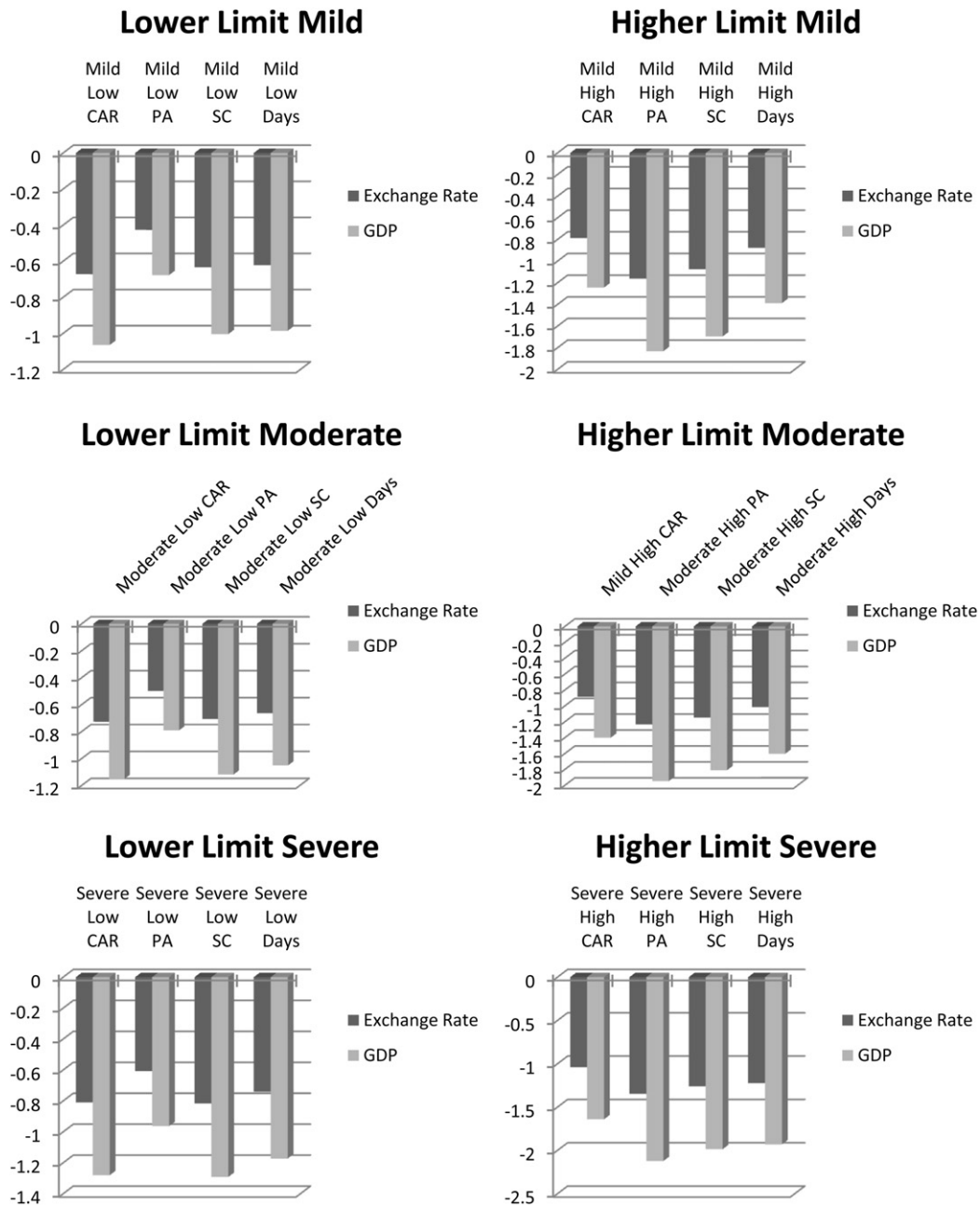


Fig. 9. Sensitivity of GDP and exchange rate.

absence modelled in our sensitivity analysis. Also, the use and effectiveness of antivirals in the CGE model are dictated by the assumptions of the model outlined in (Kramer, 2007) and are therefore subject to the same limitations as that study.

Another limitation is that the model does not account for the ability of the financial sector to increase the amount of business that is handled by unaffected parent or sister companies overseas while the pandemic occurs in the UK. It may be that using such methods the overall impact on the financial sector will be reduced, or that, for instance, the UK may see an influx of capital from Asia prior to the pandemic (on the assumption that the pandemic originates in Asia) and then an outflow during the pandemic, thus spreading the effect. It is also possible, of course, that key workers may be moved geographically, or other policies put in place in corporate preparedness plans.

Finally, the parameterization of effect in this model has concentrated upon effects on the labour supply. There are likely to be wider effects, such as problems caused through an inability to service banks or cash-machines with currency, possible minor exchange rate fluctuations or frictional effects on industry liquidity. However, it is not possible to take these into account at present as there is no information that may guide parameter estimation, and it would also require significant changes to the current modelling methods used.

Overall, the modelling approach used here has provided some interesting likely 'first order' effects of pandemic influenza and responses to it. For instance, it appears robust that antivirals will be largely ineffective and that the likely prophylactic absenteeism by workers will be most harmful to the economy. The importance of the financial sector to the large economies of the world is such that

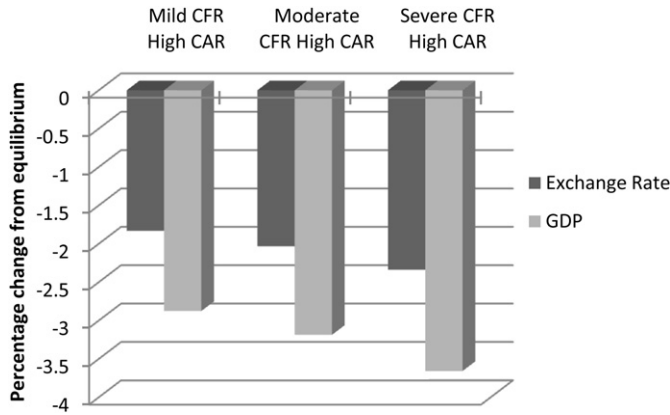


Fig. 10. GDP and exchange rate for severe sensitivity scenario.

Table 7  
Sensitivity results for 25% and 50% CAR for all scenarios.

	Exchange rate effect (%)		GDP effect (%)		Example UK cost impact (£bn)	
	25% CAR	50% CAR	25% CAR	50% CAR	25% CAR	50% CAR
	Mild disease	-0.122	-0.240	-0.194	-0.381	-2.52
Moderate disease	-0.178	-0.344	-0.283	-0.546	-3.68	-7.10
Severe disease	-0.263	-0.501	-0.417	-0.794	-5.42	-10.33
SC mild disease	-0.238	-0.350	-0.379	-0.556	-4.92	-7.22
SC moderate disease	-0.292	-0.449	-0.464	-0.712	-6.03	-9.25
SC severe disease	-0.373	-0.598	-0.592	-0.948	-7.69	-12.32
PA mild disease	-0.608	-0.729	-0.963	-1.153	-12.52	-14.99
PA moderate disease	-0.665	-0.835	-1.054	-1.320	-13.70	-17.16
PA severe disease	-0.752	-0.995	-1.190	-1.572	-15.46	-20.43
SC and PA mild	-0.672	-0.786	-1.065	-1.244	-13.84	-16.17
SC and PA moderate	-0.727	-0.887	-1.151	-1.402	-14.96	-18.23
SC and PA severe	-0.809	-1.039	-1.280	-1.641	-16.64	-21.33

further analysis would appear to be beneficial, especially if it were to account for the epidemiological effects of mitigation policies and the possibility of financial organisations shifting business to foreign branches during the pandemic peak and undertaking additional work when the pandemic strikes elsewhere. Further development of the modelling approach undertaken here together with exploration of the likely wider effects and how to parameterize these is therefore recommended. In the light of the current financial crisis, centered on the banking sector, we have in fact seen some of the ways in which any adverse impacts on that sector affect the entire UK economy. In that context it is advisable to consider the extreme vulnerability of an already compromised financial sector to the impact of a deadly respiratory disease prior to the recovery – if any – of that sector and the UK economy; a recovery which might take a decade or more.

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**Appendix. Supplementary material**

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.socscimed.2011.05.025

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