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The Global Economic Effects of Pandemic Influenza

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The Centre of Policy Studies (COPS) is a research centre at Monash University devoted to economy-wide modelling of economic policy issues.

The Global Economic Effects of Pandemic Influenza

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Abstract

We analyse the global economic effects of two influenza pandemics that represent extremes along the virulence-infectiousness continuum of possible pandemics: a high virulence-low infectiousness event and a low virulence-high infectiousness event. We do this by applying results from a susceptible-infected-recovered epidemiological model to a detailed, quarterly computable general equilibrium model. Our findings indicate that global economic activity will be more strongly affected by a pandemic with high infection rates rather than high virulence rates, all else being equal. At the regional level, regions with a higher degree of economic integration with the world economy will be affected more strongly than less integrated regions.

JEL codes: C68, E37, I18

Keywords: computable general equilibrium, pandemic influenza, quarterly periodicity

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1. Introduction

Infectious diseases are a leading cause of death worldwide, accounting for a quarter to a third of all mortality. In most industrialised countries, infectious disease ranks after cancer and heart disease as a leading cause of mortality. Despite developments in pharmaceuticals, infectious disease rates are rising due to changes in human behaviour, larger and denser cities, increased trade and travel, inappropriate use of antibiotic drugs, and the emergence of new and resurgent pathogens.

Infectious disease outbreaks can easily cross borders to threaten economic and regional stability, as has been demonstrated historically by the HIV, 2009 H1N1 influenza, H5N1, and SARS epidemics and pandemics. Emerging diseases, by definition, are not commonly encountered by physicians, and are therefore capable of generating widespread infection and mortality prior to identification of the etiologic agent (e.g., HIV/AIDS). Furthermore, the drug development and approval timeline is offset from emergence of disease and sufficiently long enough for the initial infection to result in significant mortality. The constant adaptation of microbes, along with their ability to evolve and become resistant to antibacterial and antiviral agents, ensures that infectious diseases will continue to be an ever-present and ever-changing threat. Here we estimate the possible economic effects for the world economy of a range of infection disease outbreaks. This is done by applying epidemiological and economic models.

We develop an infectious disease model (IDM) designed to provide a probabilistic view of the number of deaths that could result from a range of possible and plausible infectious disease pandemics. Scientific understanding from the disciplines of virology, epidemiology and mathematical biology was used to build an event set that allows the model to capture the characteristics of influenza and non-influenza emerging infectious disease pandemics. It is desirable to have an overall infectious disease model (one that includes influenza and non-influenza pandemics) because lethal viruses tend to displace each other, so there is a linkage between them. The event set, consisting of several thousand scenarios, represents the potential wide range of characteristics of a pandemic and likelihood of occurrence. Mortality and morbidity rates per age cohort are the output for each event and for each modelled country and country region. Using the IDM and related data, two diverse scenarios were developed and provide the basis and shocks for subsequent economic modelling.

Our economic model is a modified version of the GTAP model (Hertel and Tsigas 1997). GTAP is a multi-regional, comparative-static, computable general equilibrium (CGE) model of world trade and investment. The defining characteristic of CGE models is a comprehensive representation of the economy, i.e., as a complete system of interdependent components: industries, households, investors, governments, importers and exporters (Dixon et al. 1992). The structure of CGE models makes them well suited to analysing catastrophic events that are, by their nature, rare (Giesecke et al. 2011). An influenza pandemic is of this nature. GTAP has excellent regional and industry detail, which is important for estimating the global economic effects of influenza pandemics. Nevertheless, to capture the dynamic behaviour of an influenza pandemic we need an economic model that is also dynamic. Further, the model must be able to capture the short, sharp duration of influenza pandemics. Thus, we modify the GTAP model by incorporating dynamic mechanisms with quarterly periodicity; most CGE models are of annual periodicity. An annual model is inappropriate here as it tends to smooth out short-term effects leading to potential underestimation of disruption. We also add to the model the real world feature of inertia in the labour market (sticky real wages) so that short-run unemployment is endogenous.

Our results provide global and region-specific economic impacts of the two pandemic scenarios. The two influenza pandemic scenarios represent extremes along the virulence-infectiousness continuum of possible pandemics: a high virulence-low infectiousness event and a low virulence-high infectiousness event. The nature of the two scenarios cover a broad spectrum of possible pandemic events. As such, our results provide policy makers with useful information on the orders of magnitude of the global and regional economic effects of future pandemics.

2. The nature of influenza pandemics

2.1 Overview

Influenza mortality, which can be highly variable from year to year, is a contributor to the variability in the annual mortality rate of industrialised countries. Influenza is a contagious disease and most often affects the upper airway and lungs of birds and some mammals. It causes seasonal epidemics globally and is a leading cause of infectious disease-related deaths in most countries around the world. In non-pandemic years, influenza typically kills hundreds of thousands of people worldwide. The highest rates of mortality are in the elderly, followed by infants and children. Occasionally, flu rates can reach pandemic proportions across the global population. There have been four influenza pandemics since the beginning of the 20th century, in 1918, 1957, 1968 and 2009; each of these was a result of a major genetic change to the virus.

There have been five influenza pandemics in the past 120 years (1889, 1918, 1957, 1968, and 2009), where a novel virus circulated through the population in non-seasonal patterns, causing excess morbidity. The most severe of these was the 1918-1919 “Spanish Flu” pandemic, where influenza mortality reached as high as thirty-five times the yearly average. Most recently, May 2009 saw the emergence from Mexico of a new H1N1 virus capable of human-to-human transmission. The 2009 pandemic H1N1 virus was a novel type of influenza A, known commonly as “swine flu” due to its close association with North American and Eurasian pig influenza. Highly transmissible, yet ultimately mild, it rapidly spread around the world, infecting 74 different countries in all six continents within five weeks. The rate of spread of the pandemic was far more rapid than previously observed, enabled by high volumes of international air traffic. The WHO declared a pandemic on June 11, 2009. It ultimately reached more than 200 countries and infected hundreds of millions of people.

Despite initial fears, H1N1 had the lowest virulence characteristics of any previously measured pandemic influenza virus. Although pharmaceutical advances, efficient public health measures, and pre-existing levels of immunity reduced the impacts from this event, the low number of fatalities was predominantly the result of the genetic characteristics of the virus. The initial outbreak in Mexico had a higher case fatality rate, in the order of a percentage point, than that observed once pandemic status was reached (Presanis et al. 2009). This is likely due in part to the low seasonal flu immunity of the Mexican population and poor public health infrastructure as well as possible changes in the characteristics of the virus. In June 2010 the WHO reported over 18,000 confirmed fatalities from H1N1.

2.2 The effect on human behaviour

Direct economic effects of illness resulting from influenza include increased healthcare expenditures by patients and funders (e.g., governments, insurers), and increased workloads for healthcare workers. Indirect effects include a smaller labour supply due to deaths, and increased absenteeism from work by sick workers and by workers wishing to reduce the risk of contracting illness in the workplace, i.e., prophylactic absenteeism.

Prophylactic absenteeism is one example of voluntary risk-modifying behaviour in response to a pandemic. Other examples are reduced domestic and international travel, and reduced public gatherings at sporting and other events (Congressional Budget Office 2006). Non-voluntary risk-modifying behaviour may be imposed on workers with children by school closures intended to mitigate the spread of the virus (Beutels et al. 2008). Thus, some workers will be forced to take leave to care for young children. Workers who take paid leave from work, whether forced or voluntary, reduce their firm's labour productivity i.e., output per worker, unless other workers can fully replace output lost due to absenteeism. This may be difficult during an influenza pandemic because the virus will be widespread and while many workers may not present to the health system, they are likely to be less productive than would otherwise be the case.

It is unclear what attitudes firms have towards absenteeism during pandemics, including whether they prepare for such events or whether it affects their hiring behaviour. A related question is whether firms utilise workers differently during pandemics, e.g., do they expect present workers to work harder or longer to compensate for output lost due to absent workers? And do pandemics directly impact investment behaviour by firms? These issues have not been given much attention by pandemic researchers up to now.

Fan (2003) argues that a pandemic will reduce business investment due to increased uncertainty and risk, leading to excess capacity. Similarly, consumer confidence will decline due to uncertainty and fear, leading to reduced spending as people elect to be homebound to reduce the probability of infection—this is another example of risk-modifying behaviour. Reduced consumer confidence may particularly affect services involving face-to-face contact (e.g., tourism, transportation and retail spending). James and Sargent (2006) argue that evidence from past pandemics suggests that it is mainly discretionary spending (e.g., tourism and transportation) that is reduced.

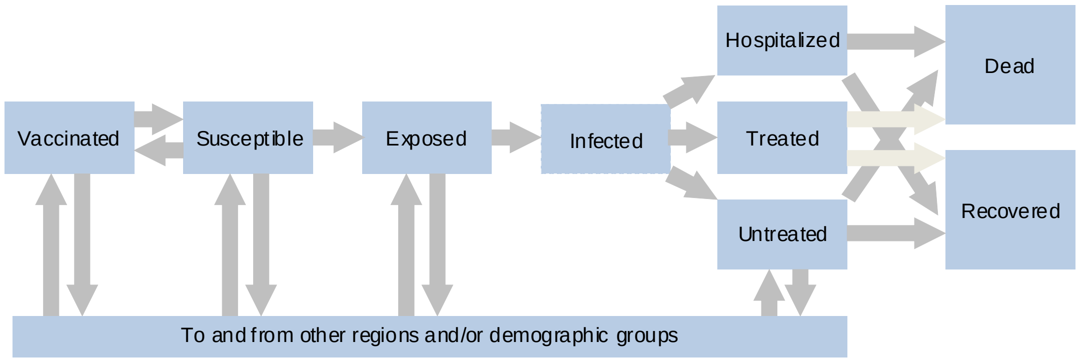
Fan (2003) also argues that an epidemic does not need to be of high morbidity and mortality in order to exert a large psychological impact on attitudes to risk. For instance, although the 2003 SARS epidemic was characterised by low morbidity and mortality, it did have a large psychological impact on attitudes to risk. James and Sargent (2006) evaluate this argument by examining evidence from the SARS epidemic and agree that people did experience increased fear of infection, e.g., 50 per cent of surveyed respondents in Taiwan reported wearing a mask during the height of SARS (p. 22). Nevertheless, they argue that the evidence indicates that the only economic impact during the SARS epidemic was on air travel to affected locations and related impacts on accommodation. Keogh-Brown and Smith (2008) perform a retrospective analysis of the economic impact of the 2003 SARS epidemic and find that the economic effects were mainly but not exclusively centred on East Asian regions, and that the effects went beyond air travel and accommodation.

3. Pandemic modelling

3.1 The model

The morbidity and mortality impact of each pandemic event on the age cohorts of the population affected are modelled using a variation on a commonly-used epidemiological approach known as the Susceptible-Infected-Recovered (SIR) model (see Britton (2003), chapter 3). The SIR Model computes the theoretical number of people infected with an infectious disease in a closed population over time. This type of modelling is applicable to diseases where an individual that has recovered from the disease is removed from the susceptible population. In order to derive the equations of the mathematical model, the population of a single region and/or demographic groups is divided into eight subpopulations: susceptible, vaccinated, exposed, three subsets of infected (untreated, hospitalised, and treated), recovered, and dead. Figure 1 displays the way the model replicates the dynamics of a pandemic.

Figure 1. Susceptible-Infected-Recovered model



The susceptible population is decreased through vaccination and exposure to the virus; conversely, it is increased by the loss of vaccine acquired immunity. Vaccinated individuals are not considered to be completely protected and become exposed at a rate much lower than the susceptible population. Vaccine efficacy can vary over the course of the epidemic. Typically, with an influenza vaccine, a period of time around one month is required after vaccination until the individual has produced sufficient antibodies for the vaccine to be effective. Even after this initial time period, vaccine efficacy will be less than 100 percent due to varying individual antibody response to vaccine and the possibility of viral mutation or imperfectly-matched vaccine. The model contains different vaccine efficacy assumptions reflected in the scenarios.

After exposure, individuals progress to one of three infected states: untreated, treated, and hospitalised. The proportion of individuals progressing into each category is dependent on viral characteristics. As the virulence of the virus increases, the proportion of the infected receiving treatment also increases. The duration of infectiousness and transmission probabilities are decreased for those receiving treatment. Through this mechanism the parameters of the model allow for the simulation of behavioural and medical quarantine.

An increase in virulence can result in a reduction of average transmissibility; individuals with a severe virus tend to be too ill to be out in the community transmitting the virus. In addition, those receiving treatment or are hospitalised will have reduced contacts and transmissibility due to precautionary measures such as masks, gloves, and isolation. Individuals remain infectious during the entire course of their clinical infection. Once they have progressed out of the infectious state they can no longer transmit the virus to others.

After infection, individuals progress to one of two groups: recovered or dead. The rate at which individuals progress from one of the three infected states (hospitalised, treated, or untreated) to the end states is dependent on virulence and level of treatment during infection. Hospitalised individuals have the highest death rate, followed by treated and untreated cases. Many of the untreated individuals likely have subclinical or asymptomatic infections, which reduces death rates despite the fact that some with untreated clinical infections may be more likely to die.

Those individuals progressing to the recovered state are considered to have immunity for the duration of the pandemic. Pandemics tend to come in waves and infect individual areas for short periods of time. It is unlikely that in the case of an influenza pandemic the strain will mutate enough to cause re-infection during a single pandemic wave. There are five morbidity states included in the pandemic model: <u>subclinical</u>, where the infected person seeks no medical attention but purchases pharmaceuticals; <u>physician and flu clinic</u>, where the infected person seeks medical attention by visiting a physician or a flu clinic; <u>hospitalisation</u>, where the infected person is hospitalised and survives; intensive care unit (ICU), where the infected person is hospitalised and spends time in an ICU and survives; and death, where the infected person is hospitalised and dies.

3.2 The scenarios

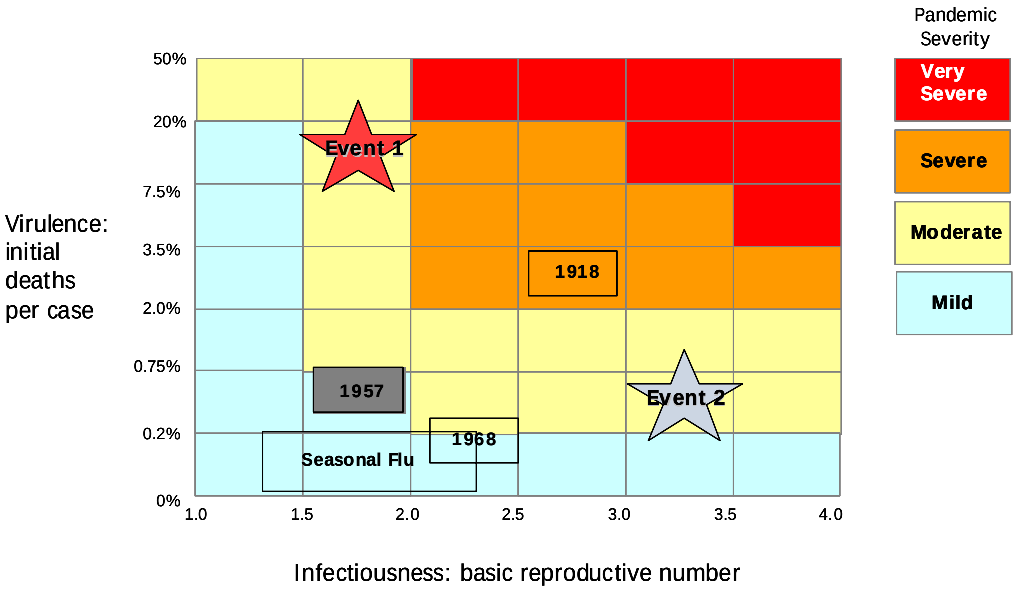
Two scenarios were modelled. Both pandemic scenarios begin in Vietnam and have a similar overall global fatality impact (~.01%), but their viral characteristics are significantly different.

Scenario 1 is a virus comparable to a transmissible version of SARS. Overall attack rates are low, in the range of 3% of the global population and it takes 6 months to develop an effective treatment beyond standard antibiotics, antivirals, and supportive care such as ventilators. The case fatality rate without intervention is 10%, similar to SARS. The virus has a disproportionate mortality effect on the working age population, comparable to the 1918 pandemic. The virus causes serious illness in most individuals and 90% of those affected require physician treatment or hospitalisation.

Scenario 2 is an extremely transmissible influenza virus with global attack rates of approximately 40%, despite the availability of an effective vaccine within months of the outbreak. The case fatality rate is 0.5%, which is similar to the case fatality rate of the 1957 influenza pandemic. Unlike seasonal influenza, where typically 90% of the fatalities are observed in individuals greater than 65, this virus has an equal case fatality across ages consistent with the 2009 H1N1 pandemic. The majority of cases are subclinical or physician visits and approximately one fifth of those hospitalized require intensive care, analogous to what is observed in seasonal outbreaks.

The pandemic scenarios were selected with viral characteristics that are plausible and less extreme than historical events, such as the 1918 pandemic. Figure 2 shows how the pathogen characteristics of the scenarios measure up against historical flu pandemics. Epidemic curves were created for each country or region using the calculated correlation between the observed 2009 H1N1 pandemic transmission timeline and country density. A log-linear relationship between population and weeks until pandemic peak represented the most appropriate statistical fit. The epidemic curves were used to develop weekly totals of individuals in each of the six morbidity classes by country or region that served as the input into the economic model.

Figure 2. Infectiousness and virulence of pandemic viruses in the twentieth century



4. The shocks

4.1 The epidemiological shocks

Hereafter, the two pandemic scenarios described above are referred to as Event 1 and Event 2. Event 1 is a high virulence-low infectiousness pandemic; Event 2 is a low virulence-high infectiousness pandemic. For each of the two scenarios, the SIR model provides estimates of the number of persons newly infected per week and the severity of their infection in each region over the course of the pandemic year. The scenarios provide the number of infection types for the total population and the working-age population by country or country grouping. Tables 1 and 2 present the number of new infections per week aggregated over the course of the pandemic year.

Figure 3 compares the severity of each pandemic event on the basis of the proportion of the population that is assumed to be infected with influenza. In terms of infection rates, Event 2 is around 12 times more severe than Event 1 for most regions. Hence, all other things being equal, we expect the economic effects of Event 2 to be around 12 times larger than those of Event 1.

Figure 4 plots the distribution of infected cases by severity. Although Event 2 is much more widespread, in terms of infections, a much smaller proportion of these infections result in death (0.5% cf. 6.9%) and a much greater proportion remain at the subclinical and physician/flu clinic levels of contact with the health system. Other things being equal, this will tend to make the reduction in the labour supply (due to deaths) much more important in Event 1 than in Event 2. Further, the much higher death rates in Event 1 are likely to create greater incentives for actions by populations to avoid contracting the pandemic, which we feel is likely to lead to much stronger negative effects on international travel, all other things equal. The much higher death rate is also likely to lead to more draconian responses by authorities regarding travel and movement by populations.

Table 1 Event 1: new infections in the pandemic year (persons)

Region[a]	Subclinical		Physician		Flu clinic		Hospital		Intensive care unit		Death	
	Total[b]	18-65[c]	Total[b]	18-65[c]	Total[b]	18-65[c]	Total[b]	18-65[c]	Total[b]	18-65[c]	Total[b]	18-65[c]
AUS	30,612	22,007	76,530	44,014	45,918	22,007	41,494	25,637	14,289	9,036	14,830	9,247
ROC	39,354	23,880	98,386	47,759	59,032	23,880	57,057	25,975	11,750	7,327	19,136	12,005
CHN	3,803,475	2,914,042	9,508,687	5,828,085	5,705,212	2,914,042	8,425,325	5,086,302	1,027,175	725,505	2,281,267	1,612,334
JPN	266,728	191,081	666,819	382,162	400,091	191,081	297,689	204,788	126,394	73,358	123,528	69,432
KOR	123,633	97,933	309,083	195,866	185,450	97,933	233,335	151,133	86,208	60,062	77,351	53,671
IND	2,863,627	1,816,309	7,159,068	3,632,617	4,295,441	1,816,309	5,242,052	2,427,531	582,215	380,259	1,454,087	959,781
IDN	629,537	434,633	1,573,842	869,265	944,305	434,633	1,133,294	584,594	133,077	90,958	359,394	247,177
SIN	12,521	25,999	31,301	51,999	18,781	9,999	26,103	14,243	4,652	3,906	6,269	4,288
ROA	2,868,003	1,812,153	3,624,307	3,624,307	4,302,005	1,812,153	5,350,471	2,443,656	1,047,101	686,811	1,637,743	1,085,382
CAN	63,796	47,988	159,490	95,976	95,694	47,988	86,706	56,621	27,583	17,811	30,111	19,161
USA	605,342	427,974	1,513,355	855,948	908,013	427,974	802,522	484,016	292,564	184,144	282,933	175,844
MEX	204,729	132,927	511,821	265,853	307,093	132,927	363,111	177,910	88,982	58,511	117,097	77,489
RNA	227	168	568	337	341	168	413	254	101	67	134	88
ARG	74,318	48,572	185,794	97,144	111,477	48,572	128,957	67,809	32,934	20,701	43,740	27,386
BRA	378,641	264,406	946,602	528,813	567,961	264,406	680,550	361,729	168,947	114,481	222,677	151,531
RSA	442,891	280,178	1,107,229	560,356	664,337	280,178	803,049	379,369	191,022	122,265	251,275	161,876
FRA	111,689	77,570	279,221	155,140	167,533	77,570	130,353	81,719	55,392	33,001	48,305	28,133
DEU	142,950	105,380	357,374	210,759	214,424	105,380	175,152	120,549	62,212	37,478	67,924	39,820
ITA	105,713	76,827	264,283	153,654	158,570	76,827	136,704	93,340	58,004	34,777	53,783	31,318
GBR	109,731	78,026	274,326	156,051	164,596	78,026	142,901	90,108	66,072	40,448	52,243	31,358
REU	406,069	306,949	1,015,173	613,898	609,104	306,949	527,861	351,854	219,064	141,375	199,860	126,571
ROE	73,735	54,496	184,337	108,992	110,602	54,496	106,184	67,349	36,876	23,709	39,158	24,841
RUS	307,129	245,531	767,822	491,063	460,693	245,531	455,651	312,417	59,047	40,734	163,630	111,322
FSU	296,227	211,381	740,569	422,761	444,341	211,381	440,859	250,287	149,757	99,605	148,456	98,527
TUR	171,123	118,548	427,808	237,096	256,685	118,548	297,711	153,306	76,148	52,116	100,372	69,215
RME	1,126,649	715,177	2,816,621	1,430,354	1,689,973	715,177	1,934,075	878,722	476,360	316,329	603,146	404,629
SA	88,272	57,029	220,680	114,058	132,408	57,029	128,755	60,208	40,090	26,686	44,285	29,795
RSA	2,340,921	1,147,965	5,852,303	2,295,930	3,511,382	1,147,965	5,315,532	1,793,736	542,943	310,829	1,064,191	617,149

Source: Authors' simulations.

[a] Australia (AUS), Rest of Oceania (ROC), China (CHN), Japan (JPN), Korea (KOR), India (IND), Indonesia (IDN), Singapore (SIN), Rest of Asia (ROA), Canada (CAN), United States of America (USA), Mexico (MEX), Rest of North America, (RNA), Argentina (ARG), Brazil (BRA), Rest of South America, Central America, Caribbean (RSA), France (FRA), Germany (DEU), Italy (ITA), Great Britain (GBR), Rest of European Union (REU), Rest of Europe (ROE), Russia (RUS), Former Soviet Union (FSU), Turkey (TUR), Rest of Middle East, North Africa (RME), South Africa (SA), Rest of Sub-Saharan Africa (RSA). [b] New infections for the total population. [c] New infections amongst the working-age population (18-65 years).

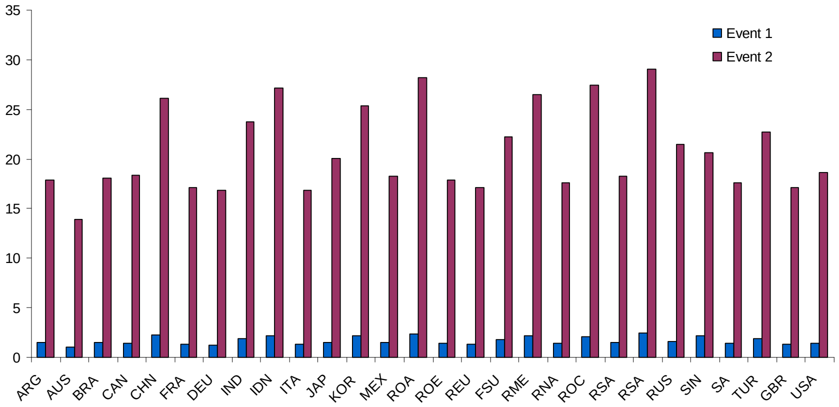
Table 2 Event 2: new infections in the pandemic year (persons)

Region[a]	Subclinical		Physician		Flu clinic		Hospital		Intensive care unit		Death	
	Total[b]	18-65[c]	Total[b]	18-65[c]	Total[b]	18-65[c]	Total[b]	18-65[c]	Total[b]	18-65[c]	Total[b]	18-65[c]
AUS	2,295,892	1,320,431	229,589	66,022	344,384	132,043	13,719	9,251	2,362	1,821	14,001	8,151
ROC	2,951,581	1,432,781	295,158	71,639	442,737	143,278	15,375	5,283	1,999	1,255	17,328	8,933
CHN	285,260,608	174,842,546	28,526,061	8,742,127	42,789,091	17,484,255	1,771,532	964,643	161,938	131,205	1,722,813	1,088,143
JPN	20,004,566	11,464,856	2,000,457	573,243	3,000,685	1,146,486	114,343	88,562	21,696	15,471	126,914	70,984
KOR	9,272,485	5,875,971	927,249	293,799	1,390,873	587,597	55,379	33,933	8,943	7,535	57,093	36,746
IND	214,772,042	108,978,524	21,477,204	5,448,926	32,215,806	10,897,852	1,123,362	402,751	98,405	65,227	1,244,666	671,237
IDN	47,215,259	26,077,957	4,721,526	1,303,898	7,082,289	2,607,796	231,592	97,184	21,540	15,740	279,691	162,242
SIN	740,273	515,758	94,027	25,288	106,041	59,576	5,554	3,691	821	676	5,302	3,457
ROA	215,100,261	108,729,206	21,510,026	5,436,460	32,265,039	10,872,921	1,286,926	480,480	166,747	118,270	1,255,582	674,668
CAN	4,784,702	2,879,282	478,470	143,964	717,705	287,928	25,903	17,649	4,474	3,548	26,958	16,338
USA	45,400,642	25,678,441	4,540,064	1,283,922	6,810,096	2,567,844	254,711	159,815	48,108	36,454	275,404	158,585
MEX	15,149,531	7,975,594	1,514,953	398,780	2,272,430	797,559	87,266	35,523	13,987	10,201	88,836	49,122
RNA	17,028	10,097	1,703	505	2,554	1,010	84	40	15	12	104	63
ARG	5,514,216	2,914,322	551,422	145,716	827,132	291,432	29,541	12,528	4,928	3,616	33,040	18,041
BRA	28,398,052	15,864,380	2,839,805	793,219	4,259,708	1,586,438	158,488	69,391	26,538	19,978	167,959	97,966
RSA	33,216,856	16,810,668	3,321,686	840,533	4,982,528	1,681,067	192,296	74,167	30,004	21,327	194,089	103,681
FRA	8,376,639	4,654,196	837,664	232,710	1,256,496	465,420	42,823	29,263	8,200	5,937	47,432	26,396
DEU	10,721,222	6,322,777	1,072,122	316,139	1,608,183	632,278	61,945	46,692	10,516	7,740	67,556	39,190
ITA	7,928,497	4,609,607	792,850	230,480	1,189,275	460,961	45,094	34,018	9,478	6,961	49,879	28,501
GBR	8,229,789	4,681,534	822,979	234,077	1,234,468	468,153	47,303	32,062	7,169	5,345	50,747	28,913
REU	30,455,192	18,416,934	3,045,519	920,847	4,568,279	1,841,693	176,997	126,982	36,206	28,466	188,147	113,619
ROE	5,530,112	3,269,748	553,011	163,487	829,517	326,975	29,349	18,376	5,778	4,510	34,050	20,298
RUS	23,034,655	14,731,875	2,303,466	736,594	3,455,198	1,473,188	112,286	80,248	9,746	8,021	143,246	92,250
FSU	22,217,056	12,682,844	2,221,706	634,142	3,332,558	1,268,284	143,196	88,807	24,348	19,330	134,159	78,936
TUR	12,834,229	7,112,868	1,283,423	355,643	1,925,134	711,287	78,098	40,954	11,885	9,450	75,640	43,999
RME	84,498,644	42,910,626	8,449,864	2,145,531	12,674,797	4,291,063	577,466	315,333	72,664	59,071	487,101	263,164
SA	6,620,404	3,421,740	662,040	171,087	993,061	342,174	41,247	22,919	6,334	5,056	38,486	21,122
RSA	175,569,077	68,877,905	17,556,908	3,443,895	26,335,361	6,887,791	1,216,222	286,530	100,505	52,177	993,634	425,410

Source: Authors' simulations.

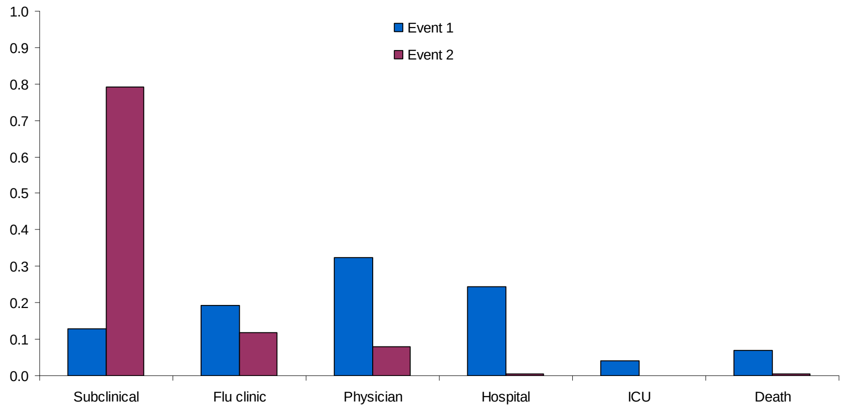
[a] Australia (AUS), Rest of Oceania (ROC), China (CHN), Japan (JPN), Korea (KOR), India (IND), Indonesia (IDN), Singapore (SIN), Rest of Asia (ROA), Canada (CAN), United States of America (USA), Mexico (MEX), Rest of North America, (RNA), Argentina (ARG), Brazil (BRA), Rest of South America, Central America, Caribbean (RSA), France (FRA), Germany (DEU), Italy (ITA), Great Britain (GBR), Rest of European Union (REU), Rest of Europe (ROE), Russia (RUS), Former Soviet Union (FSU), Turkey (TUR), Rest of Middle East, North Africa (RME), South Africa (SA), Rest of Sub-Saharan Africa (RSA). [b] New infections for the total population. [c] New infections amongst the working-age population (18-65 years).

Figure 3. Infection rates in Events 1 and 2 (% of population)



Legend: Australia (AUS), Rest of Oceania (ROC), China (CHN), Japan (JPN), Korea (KOR), India (IND), Indonesia (IDN), Singapore (SIN), Rest of Asia (ROA), Canada (CAN), United States of America (USA), Mexico (MEX), Rest of North America, (RNA), Argentina (ARG), Brazil (BRA), Rest of South America, Central America, Caribbean (RSA), France (FRA), Germany (DEU), Italy (ITA), Great Britain (GBR), Rest of European Union (REU), Rest of Europe (ROE), Russia (RUS), Former Soviet Union (FSU), Turkey (TUR), Rest of Middle East, North Africa (RME), South Africa (SA), Rest of Sub-Saharan Africa (RSA).

Figure 4. Distribution of cases in Events 1 and 2 (% of total infections)



4.2 The economic shocks

Previous analyses of pandemics and their potential economic effects highlight a number of channels through which an economy might be affected by a serious outbreak of influenza (see Fan 2003; Congressional Budget Office 2006; James and Sargent 2006; Jonung and Roeger 2006; Chou et al. 2004; Lee and McKibbin 2004; McKibbin and Sidorenko 2006; Beutels et al. 2008; Keogh-Brown and Smith 2008; Keogh-Brown et al. 2010; Dixon et al. 2010). These channels include: reduced consumption by households on tourism, transportation and retail spending; increased absence from the workplace due to illness or for prophylaxis; school closures; and higher demands for medical services. Considering these channels, we decide on four types of economic shocks to simulate an influenza pandemic:

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

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

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

(4) temporary reductions in inbound and outbound international tourism and business travel.

We describe below how the number of persons in each infection category are translated into shocks to our CGE model.

4.2.1 Increased demand for medical services

Each pandemic event generates an increase in demand for medical services relative to baseline (or business-as-usual). In calculating the resulting increase in medical spending, we began by collecting information on expected case costs in the USA and Australia. In particular, on the basis of costs reported in Dixon et al. (2010) and Verikios et al. (2010) we assume that:

- all subclinical cases spend $US3 (2009 dollars) on pharmaceuticals in the USA and $US5 in Australia;
- all flu clinic and physician cases cost $US293 (2009 dollars) in the USA and $US61 in Australia;
- all hospital cases cost $US18,293 (2009 dollars) in the USA and $US3,564 in Australia;
- all ICU cases cost $US85,395 (2009 dollars) in the USA and $US18,298 in Australia; and
- all deaths cost $US46,120 (2009 dollars) in the USA and $US12,356 in Australia.

For all other regions in our model, we assume the per case cost of each infection type (in $US) is proportional to the region's per capita health spending relative to Australia. Increased medical spending related to each pandemic is applied as increased expenditure on the *Government services* sector (see Table 3 below).

4.2.2 Lost workdays

Each pandemic event causes lost work days via two routes: workers falling ill and parents caring for children. In calculating lost work days from workers falling ill, we assume that:

- each subclinical case of working age misses 0.5 workdays;
- each flu clinic and physician case of working age misses 2.4 workdays;
- each hospital and ICU case of working age misses 13.9 workdays.[3]

The total number of workdays lost in each region is then adjusted for the proportion of persons employed in the region.

The second effect relates to parents staying home to mind children, either because (i) the children are sick and are not allowed to attend school, or (ii) schools have been closed by authorities for prophylactic purposes. We calculate lost parent workdays as a proportion (75%) of workdays lost due to workers falling ill. The proportion is based on the relative size of these two effects calculated in Dixon et al. (2010), which models the economic impacts of an influenza pandemic for the USA.[4]

Once total lost workdays have been calculated, we compare our estimate of each region's total lost workdays (from both effects) to an estimate of each region's business-as-usual total number of quarterly workdays and calculate the proportional reduction in labour productivity (output per worker) due to illness.

4.2.3 Reductions in inbound tourism

We assume that inbound tourism is a positive function of both the number of persons infected in each event and the initial deaths per case. For Event 2 (high infectiousness-low virulence) we use an infection/tourism relationship whereby a 30% infection rate leads to a 34% reduction in inbound tourism in each quarter where new infections occur. This relationship is based on estimates applied in Dixon et al. (2010). For Event 1 (low infectiousness-high virulence) we adjust the infection/tourism relationship by initial deaths per case so that a 30% infection rate leads to a 70% reduction in inbound tourism in each quarter where new infections occur. This approximate doubling of the strength of the infection/tourism relationship is based on our assumption of higher risk-modifying behaviour in Event 1 given that the virulence (initial deaths per case) is around 20 times higher than in Event 2.

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[3] Per capita workday losses (for workers and parents) were estimated by Molinari et al. (2007) for working age persons (18-64 years) in their study of seasonal influenza in the US; their estimates take account of workforce participation rates.

[4] The calculation of the lost workdays in Dixon et al. (2010) is also based on estimates by Molinari et al. (2007).

In both events, negative tourism effects are observed in any quarter of 2010 where new infections occur in a region. We assume that tourism does not begin to recover for all regions until no new infections are observed in any region, i.e., 2011. We then calculate a smooth recovery path for inbound tourism in all regions that takes place over the four quarters of 2011.

4.2.4 Permanent reductions in the labour force

Deaths of working-age are assumed to reduce the workforce permanently as a proportion of the existing workforce in each region.

5. The economic model

In modelling the economic consequences of the influenza pandemics, we apply a modified version of the GTAP model. GTAP is extensively documented in Hertel and Tsigas (1997). Here we provide only a brief description of the model. We then describe the modifications made to GTAP to create the model used for this report.

5.1 The GTAP model

GTAP is a multi-regional, comparative-static, computable general equilibrium (CGE) model of world trade and investment that represents markets as perfectly competitive, industry technologies as linearly homogeneous, and traded goods as imperfectly substitutable.[5] The defining characteristic of CGE models is a comprehensive representation of the economy, i.e., as a complete system of interdependent components: industries, households, investors, governments, importers and exporters (Dixon et al. 1992).

5.1.1 Implementing and solving the GTAP model

Formally, GTAP 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

$$A\boldsymbol{v} = \mathbf{0}\,, \qquad (1)$$

where A is an $m \times p$ matrix of coefficients, $\boldsymbol{v}$ is a $p \times 1$ vector of percentage changes (or changes) in model variables and $\mathbf{0}$ is a $p \times 1$ null vector. Of the p variables, e are exogenous (e.g., tariff rates,

[5] This is version 6.2, which is available at https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1367.

technology, household preferences, etc). 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 in the $(p-e)$ variables as linear functions of the percentage changes in the e variables. To do this, we rearrange (1) as

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

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

$$\boldsymbol{n} = -A_n^{-1}A_x\boldsymbol{x}. \qquad (2)$$

Computing solutions to an economic model using (2) and assuming the coefficients of the A matrices are constant is the method pioneered by Johansen (1960).

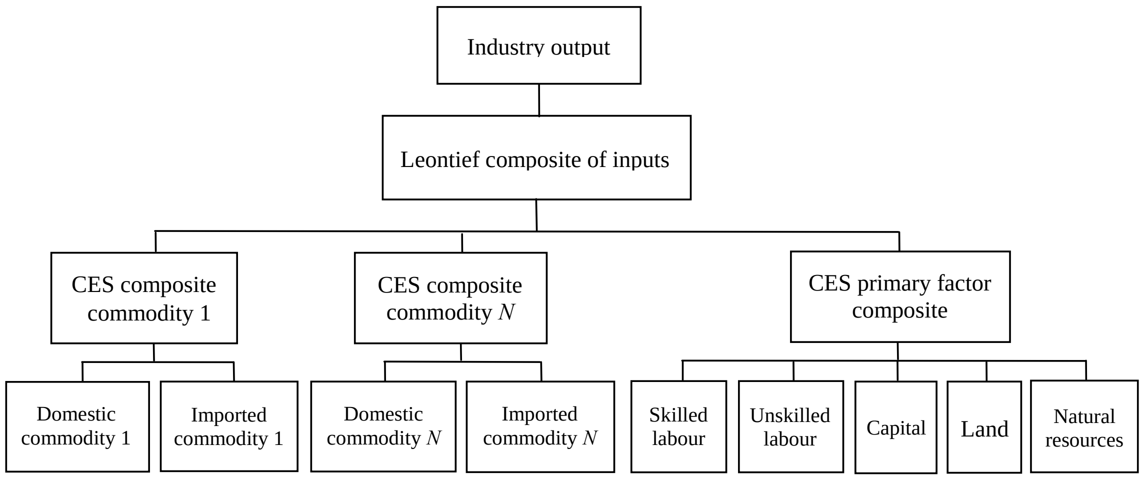
Equations (1) represent the percentage-change forms of the nonlinear functions underlying the model; these forms are derived by total differentiation. Thus, (1) is an approximation based on marginal changes in the independent variables. So (2) only provides an approximate solution to the endogenous variables $\boldsymbol{n}$; for marginal changes in $\boldsymbol{x}$ the approximation is accurate but for discrete changes in $\boldsymbol{x}$ the approximation will be inaccurate. The problem of accurately calculating $\boldsymbol{n}$ for large changes in $\boldsymbol{x}$ is equivalent to allowing the coefficients of the A matrices to be nonconstant. The problem is solved by breaking the change in $\boldsymbol{x}$ into i equal percentage changes. The multistep solution procedure requires that there are $(i-1)$ intermediate values of the underlying (levels) values of $\boldsymbol{n}$, i.e., $\boldsymbol{N}$. The intermediate values of $\boldsymbol{N}$ are obtained by successively updating the values of $\boldsymbol{N}$ after each of the i steps is applied. Once the values of $\boldsymbol{N}$ are updated for any given step, the coefficients of the $\boldsymbol{A}$ matrices in (2) are recomputed before (2) is solved again.[6]

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

5.1.2 GTAP theory

GTAP represents the world economy by modelling economic activity occurring within and between regional economies. A regional economy may be either a single country (e.g., Australia) or a composite region consisting of many countries (e.g., the European Union). Each region produces a distinct variety of each commodity, which is imperfectly substitutable with the varieties produced by other regions. Within each region, each commodity is produced by a single-product industry from inputs of domestically-produced and imported commodities and five primary factors: skilled and unskilled labour, capital, land and natural resources, as illustrated in figure 3.

Figure 5. Structure of industry production technology in GTAP



Each industry input has an *ad valorem* tax associated with it. Further, industry inputs of each composite commodity and primary factor have technical efficiency terms associated with them. Thus the model user can vary intermediate input taxes, primary factor input taxes and the efficiency with which inputs are used.

Each primary factor is supplied to industries from a fixed regional endowment of the factor. The supplies of skilled and unskilled labour and capital are perfectly transformable between industries within a region, while land is supplied with a unitary transformation elasticity and natural resources with a transformation elasticity close to zero. Consequently, wages for each category of labour and the user price of capital are uniform across industries, but the rental prices of land and natural resources can vary across industries.

Regional primary factor payments each have an income tax applied to them. Commodities produced in each region are either used as intermediate inputs in production, consumed as inputs to final demand, or exported. There are three categories of final demand: investment, government consumption and private consumption. Each of these final demand categories uses composite commodities that are constant elasticity of substitution (CES) combinations of the domestic and the imported variety of each commodity, similar to composite commodity inputs for industries (Figure 5). Composite commodity inputs to investment are used in fixed proportions. Composite commodity inputs to government consumption are determined by the maximisation of a Cobb-Douglas utility function of these inputs, while a constant-difference-elasticity (CDE) utility function is used for private consumption.

Aggregate government and private consumption are determined by the allocation of net (of depreciation) national income between government consumption, private consumption and net (of depreciation) saving to maximise a Cobb-Douglas utility function with variable scale and share parameters. Therefore, nominal government consumption, private consumption and net (of depreciation) saving are almost fixed shares of nominal national income. Foreign income flows in GTAP are zero, so that national income is equal to primary factor returns plus tax revenue minus subsidies.

Exports fall into two categories: commodities that are sold to other regions, and sales to an international pool of freight and insurance services that is used to convey internationally traded commodities from source to destination regions. This international pool is a Cobb-Douglas aggregate of the contributions from all industries in all regions. Plainly, the contributions of most industries will be zero. Only services sectors, such as trade and transport and insurance, produce outputs that could contribute to such a pool. The quantity of freight and insurance services used to convey a particular commodity from a source to destination region is proportional to the quantity of commodity transported, subject to a change in the efficiency of conveyance for that commodity and trade route.

The total regional imports of each commodity are a CES composite of imports of the commodity from each exporting region. The prices determining the allocation of total imports among exporters is the domestic market price in the exporting region, plus (minus) export taxes (subsidies), plus the price of international freight and insurance costs per unit of the commodity, plus import tariffs. Thus the choice among sources of imports occurs at the economy-wide level, while the choice between the domestic and the imported (aggregated across sources) varieties of each commodity occurs at the level of agents within the economy, that is, industries and final demands.

5.2 A dynamic version of GTAP

The GTAP model has two important advantages as a tool for estimating the economic effects of influenza pandemics: it has excellent regional and industry detail. But to capture the dynamic behaviour of an influenza pandemic we need an economic model that is also dynamic. Further, the model must be able to capture the short, sharp duration of influenza pandemics; this is the nature of past pandemics (e.g., 1919, 1957, 1968 and 2009) and the two pandemics modelled in Section 1. Thus we modify the GTAP model by incorporating dynamic mechanisms with quarterly periodicity. Quarterly behaviour is an uncommon characteristic of CGE models: most models are of annual periodicity. An annual model is inappropriate here as it tends to smooth out short-term effects leading to potential underestimation of disruption. For example, if a pandemic 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. These modifications and others are described below.

5.2.1 Capital accumulation

In comparative-static GTAP, the capital stock used by firms in each region is fixed. To move to a dynamic, discrete-time framework with annual periodicity we add an equation linking beginning-of-period capital stocks and end-of-period capital stocks per period

$$KE_r^t = KB_r^t + I_r^t - D_r; \qquad (3)$$

where KB_r^t and KE_r^t are the quantity of capital available for use in region *r* at the beginning and end of year *t*, I_r^t is the quantity of new capital created (i.e., investment) in region *r* during year *t*, and D_r^t is depreciation of capital in region *r*. With I_r^t and D_r^t representing annual values, KE_r^t in (3) will grow at an annual rate.

To define a quarterly rate of capital accumulation (signified here by superscript q rather than t) with no change in the values of any variable in (3), we add the following equation to the model,

$$KE_r^q = KB_r^q + I_r^q - D_r^q . \qquad (4)$$

In deriving (4), we create quarterly values for depreciation, D_r^q, and investment, I_r^q, that ensure KE_r^q accumulates at a quarterly rate.

In the annual model, KB_r^t is set to reflect the rate of growth of the capital stock in the initial solution (i.e., the initial data). This rate of growth is function of the initial value of the capital stock, investment, and depreciation. So if the initial data is for 2008, then our initial solution is for 2008 and the first year of our annual simulation will be a solution for 2009. In the quarterly model, we still use 2008 as our initial data but we apply quarterly values for depreciation and investment to determine the quarterly rate of growth of the capital stock in the initial solution. So our initial data period is reinterpreted as the last quarter of 2008 (2008:4) and the first period of our model simulation becomes 2009:1.

Note that (3) remains in the model and KE_r^t continues to be used in the equation that postulates a relationship between the rates of return on capital and capital growth rates (see below). Thus, the relationship between rates of return on capital and capital growth rates (i.e., investment) remains an annual one even though the periodicity of the model is now quarterly. This assumes that firms still make investment plans over a one year time horizon, but only one-quarter of those plans come online in the current period. Thus, KE_r^t and I_r^t are never realised, they are only planning variables.

5.2.2 Planned and actual investment

Planned investment in each region I_r^t is a function of the relative rate of return on capital in each region

$$I_r^t = \left(\frac{ROR_r}{ROR} \right)^{\gamma} ; \qquad (5)$$

where ROR_r $\left(ROR \right)$ is the net (of depreciation) rate of return on capital in the r-th region (globally), and γ is a positive parameter. Equation (5) ensures investment will be higher in regions with higher rates of return and vice versa. We set γ = 1, giving a unitary rate of return elasticity of investment for all regions. Actual investment in each region I_r^q is then $\frac{I_r^t}{4}$.

5.2.3 Labour supply and labour-market clearing

In each region we define the labour supply LS_r as a fixed proportion $LSRAT_r$ of the population POP_r

$$LS_r = LSRAT_r POP_r . \tag{6}$$

As GTAP defines two types of labour (skilled and unskilled), we also define the supply of labour type *l* in each region LS_{lr} as

$$\frac{LS_{lr}}{LS_r} = A_{lr}\left[\left(\frac{PW_{lr}}{PW_r}\right)^{\beta}\right]; \tag{7}$$

where PW_{lr} is the post-tax wage received by labour type *l* in region *r*, PW_r is the average post-tax wage received by labour in region *r*, and A_{lr} and β are positive parameters. Thus, labour supply by labour type is a positive function of relative wage received by each labour type. We set the labour supply elasticity β = 0.15, making labour supply only slightly responsive to relative wages in each regions. A_{lr} is a scaling factor that is set to ensure equality between each side of (7) in the initial solution.

In comparative-static GTAP, employment of each labour type in each region LD_{lr} is fixed. With LS_{lr} now defined in (7), we make LD_{lr} endogenous and add the labour-market-clearing condition

$$LS_{lr} = LD_{lr} . \tag{8}$$

Equation (8) now determines the pre-tax wage received by labour type *l* in region *r* W_{lr} by equating labour demand and supply.

5.2.4 The price of natural resources

GTAP defines natural resources (e.g., land) as a factor of production for agricultural and mining industries; these industries potentially face diminishing returns to natural resources. With natural resources fixed in a baseline simulation in which the world economy is growing, the rising demand for the output of extractive industries (i.e., coal, oil and gas) leads to implausible long-run increases in their prices. To avoid this, in the baseline we make the supply of natural resources endogenous for the extractive industries and add the price rule

$$\frac{PNR_{jr}}{PNR_{r}} = FPNR_{jr}, \quad j = Coal, Oil, Gas. \tag{9}$$

If we set the shift term $FPNR_{jr}$ as exogenous with a zero shock and the supply of natural resources for the *j*-the industry as endogenous, equation (9) allows the supply of natural resources for the *j*-the industry to grow adequately to prevent the industry's price of natural resources PNR_{jr} from growing any more (or less) quickly than the average price of natural resources in region *r* PNR_{r}. This is our approach in the baseline simulation. In the policy simulation (where we simulate a pandemic), we make $FPNR_{jr}$ endogenous and PNR_{jr} exogenous and shocked by its baseline values.

5.2.5 Sticky real wages

In our baseline simulation with our dynamic version of GTAP, we adopt the standard GTAP assumption of real wages adjusting fully to clear the labour market in every period. By contrast, our policy simulation adopts the Dixon and Rimmer (2002) wage adjustment mechanism, which makes real wages sticky or sluggishly adjusting in the short run but more flexible in the long run. Thus, in response to any shocks to the economy, employment will adjust more than real wages in the short run whereas employment will adjust less than real wages in the long run. This outcome is achieved by adding to the model an equation that controls the deviation of employment from the baseline simulation. This equation assumes that in policy simulations, the deviation in the real wage from the baseline level increases at a rate that is proportional to the deviation in the gap between employment and labour supply from its basecase level:

$$\left\{\frac{PWR_{lr}^{t}}{PWR_{lr}^{bt}} - 1\right\} = \left\{\frac{PWR_{lr}^{t-1}}{PWR_{lr}^{bt-1}} - 1\right\} + \alpha\left\{\frac{LD_{lr}^{t}}{LD_{lr}^{bt}} - \frac{LS_{lr}^{t}}{LS_{lr}^{bt}}\right\} + U^{t}, \ \forall t. \tag{10}$$

In (10), PWR_{lr}^{t} and PWR_{lr}^{bt} are the (post-tax) real wage rates in year *t* in policy and baseline simulations, LD_{lr}^{t} and LS_{lr}^{t} are employment and labour supply in year *t* in the policy simulation, LD_{lr}^{bt} and LS_{lr}^{bt} are employment and labour supply in year *t* in the baseline simulations, U^{t} is a slack variable set exogenously at zero to activate the equation in the policy simulation, and α is a positive parameter.

The relationship between real wage and employment deviations from baseline is controlled by α. We set $\alpha = 0.5$, a value that ensures that the employment deviations generated by a shock to the economy are approximately zero after about five years. In a quarterly model we wish this relationship to continue to hold. Hence we divide the parameter by four so that the employment deviations of a shock to the economy are approximately zero after about twenty quarters, i.e., $\alpha = 0.125$.

In the above specification of sticky wages [equation (10)], real wages respond symmetrically to labour market conditions whether the economy is experiencing a recession or an expansion. This is in contrast to empirical evidence suggests that real wages tend to be stickier downwards (i.e., during a recession) than they are upwards (i.e., during an expansion). As a consequence, employment tends to rise more quickly during a recession than it falls during an expansion; that is, real wages and employment respond asymmetrically to positive and negative labour conditions.[7] To account for the possibility of asymmetric real wage behaviour, we undertake sensitivity analysis in Section 6.3 in which we introduce an alternative sticky wage equation following Dixon and Rimmer (2011) whereby α in (10) is set as

$$\alpha_{lr}^{t} = 0.5, \qquad LDEV_{lr}^{t} \le 1; \quad (11)$$

$$\alpha_{lr}^{t} = \frac{\varepsilon}{\exp\left[\left\{LDEV_{lr}^{t} - LDEVMAX_{lr}^{t}\right\}^{\zeta}\right] - 1}, \qquad LDEV_{lr}^{t} > 1; \quad (12)$$

where

$$LDEV_{lr}^{t} = \frac{LD_{lr}^{t}}{LD_{lr}^{bt}}.$$

Thus, where employment in the policy simulation is equal to or below its basecase level α takes its standard value [equation (11)]. Once employment in the policy simulation moves above its baseline level, α is defined by (12). Equation (12) includes a maximum employment deviation in $LDEVMAX_{lr}^{t}$; this is set to 1.02. Using values of 1.7 and 0.5 for ε and ζ means that α will jump to around 12 when the employment deviation moves slightly above one and will peak at around 37 when it reaches $LDEVMAX_{lr}^{t}$.

[7] This phenomenon is referred to as *hysteresis* and is discussed in Romer (2001), pp. 440–4.

5.2.6 Data

To calibrate the model, we use the latest version of the GTAP database–Version 7 (Naranayan and Walmsley 2008). We aggregate the original data from 113 regions and 57 sectors to 28 regions and 30 sectors (Table 3). Besides the parameter values discussed in earlier sections, we adopt many of the original GTAP values for other parameters with some minor exceptions. Table 4 lists the parameters we apply in our implementation of the model.

Table 3 Regions and sectors in model database

Regions	Sectors
1. Australia (AUS)	1. Agriculture (AGR)
2. Rest of Oceania (ROC)	2. Coal (COA)
3. China (CHN)	3. Oil (OIL)
4. Japan (JPN)	4. Gas (GAS)
5. Korea (KOR)	5. Other minerals (OMN)
6. India (IND)	6. Processed food (PRF)
7. Indonesia (IDN)	7. Beverages and tobacco products (BTP)
8. Singapore (SIN)	8. Textiles, wearing apparel (TWA)
9. Rest of Asia (ROA)	9. Leather, wood products (LWP)
10. Canada (CAN)	10. Paper products, publishing (PPP)
11. United States of America (USA)	11. Petroleum, coal products (PET)
12. Mexico (MEX)	12. Chemicals, rubber, plastics (CRP)
13. Rest of North America (RNA)	13. Other mineral products (OMP)
14. Argentina (ARG)	14. Metals, metal products (MMP)
15. Brazil (BRA)	15. Motor vehicles and parts (MVP)
16. Rest of South America, Central America, Caribbean (RSA)	16. Other transport equipment (OTE)
17. France (FRA)	17. Electronic equipment (ELE)
18. Germany (DEU)	18. Other manufacturing (MAN)
19. Italy (ITA)	19. Utilities (UTL)
20. Great Britain (GBR)	20. Construction (CON)
21. Rest of European Union (REU)	21. Trade (TRA)
22. Rest of Europe (ROE)	22. Air transport (ATR)
23. Russia (RUS)	23. Other transport (OTR)
24. Former Soviet Union (FSU)	24. Communication (COM)
25. Turkey (TUR)	25. Other financial services (FIN)
26. Rest of Middle East, North Africa (RME)	26. Insurance (INS)
27. South Africa (SA)	27. Other business services (BUS)
28. Rest of Sub-Saharan Africa (RSA)	28. Recreation, other services (REC)
	29. Government services (GOV)
	30. Dwellings (DWE)

Table 4 Parameter values in model database

Sector	Elasticity of substitution among:[a]				
	domestic & imported goods	imported goods from different regions	goods consumed by government	intermediate inputs used by firms	factors of production
AGR	2.37	4.77	0.5	0	0.22
COA	3.05	6.10	0.5	0	0.20
OIL	5.20	10.40	0.5	0	0.20
GAS	5.20	10.40	0.5	0	0.20
OMN	0.90	1.80	0.5	0	0.20
PRF	2.72	5.59	0.5	0	1.12
BTP	1.15	2.30	0.5	0	1.12
TWA	3.73	7.46	0.5	0	1.26
LWP	3.58	7.30	0.5	0	1.26
PPP	2.95	5.90	0.5	0	1.26
PET	2.10	4.20	0.5	0	1.26
CRP	3.30	6.60	0.5	0	1.26
OMP	2.90	5.80	0.5	0	1.26
MMP	3.55	7.23	0.5	0	1.26
MVP	2.80	5.60	0.5	0	1.26
OTE	4.30	8.60	0.5	0	1.26
ELE	4.40	8.80	0.5	0	1.26
MAN	3.99	8.03	0.5	0	1.26
UTL	0.00	0.00	0.5	0	1.26
CON	0.50	1.00	0.5	0	1.40
TRA	0.10	0.10	0.5	0	1.68
ATR	1.90	3.80	0.5	0	1.68
OTR	0.50	1.00	0.5	0	1.68
COM	0.00	0.00	0.5	0	1.26
FIN	0.00	0.00	0.5	0	1.26
INS	0.00	0.00	0.5	0	1.26
BUS	0.00	0.00	0.5	0	1.26
REC	0.10	0.10	0.5	0	1.26
GOV	0.00	0.00	0.5	0	1.26
DWE	0.00	0.00	0.5	0	1.26

[a] These values apply to all regions.

Table 5 Baseline labour supply growth rates (percentage change)

Region	Year[a, b]					
	2010	2011	2012	2013	2014	2015
AUS	1.26	1.16	1.05	0.96	0.88	0.82
ROC	2.10	2.06	2.02	1.98	1.94	1.90
CHN	0.74	0.66	0.58	0.49	0.39	0.29
JPN	-0.59	-0.63	-0.66	-0.67	-0.65	-0.61
KOR	0.80	0.74	0.68	0.61	0.55	0.49
IND	1.93	1.89	1.85	1.81	1.77	1.72
IDN	1.71	1.65	1.58	1.53	1.48	1.44
SIN	0.00	0.00	0.00	0.00	0.00	0.00
ROA	2.12	2.06	2.00	1.93	1.86	1.80
CAN	1.37	1.23	1.08	0.95	0.82	0.72
USA	0.89	0.88	0.86	0.83	0.80	0.76
MEX	1.85	1.79	1.74	1.67	1.59	1.51
RNA	0.89	0.88	0.86	0.83	0.80	0.76
ARG	1.67	1.58	1.50	1.43	1.36	1.29
BRA	1.65	1.57	1.49	1.42	1.36	1.30
RSA	2.06	2.01	1.97	1.91	1.85	1.78
FRA	0.32	0.22	0.12	0.04	-0.02	-0.06
DEU	0.43	0.31	0.20	0.08	-0.04	-0.16
ITA	0.26	0.12	-0.01	-0.13	-0.24	-0.34
GBR	0.72	0.64	0.56	0.49	0.44	0.40
REU	0.42	0.32	0.23	0.14	0.08	0.02
ROE	0.42	0.34	0.27	0.20	0.15	0.11
RUS	0.09	-0.09	-0.26	-0.41	-0.53	-0.64
FSU	0.92	0.80	0.68	0.56	0.46	0.36
TUR	1.17	1.19	1.19	1.18	1.15	1.11
RME	2.36	2.21	2.06	1.94	1.86	1.79
SA	1.39	1.15	0.93	0.76	0.67	0.63
RSA	2.98	2.99	3.00	3.00	3.00	3.00

Source: International Labour Organization, Labour Statistics Database, .Economically Active Population Estimates and Projections, Table E5 (see http://laborsta.ilo.org/applv8/data/EAPEP/eapep_E.html).

a Prior to 2010, our baseline incorporates historical population growth rates also from the International Labour Organization.
b These annual growth rates are converted to quarterly growth rates before being applied to the model.

Table 6 Baseline GDP growth rates (percentage change)

Region	Year[a, b]					
	2010	2011	2012	2013	2014	2015
AUS	2.96	3.47	3.47	3.32	3.26	3.16
ROC	4.88	3.34	3.05	2.80	3.06	2.63
CHN	10.04	9.91	9.79	9.66	9.63	9.48
JPN	1.90	1.97	2.04	1.79	1.81	1.73
KOR	4.51	5.05	4.14	4.11	3.99	4.00
IND	8.78	8.43	8.03	8.09	8.10	8.08
IDN	6.00	6.20	6.50	6.70	7.00	7.00
SIN	5.68	5.29	5.07	4.71	4.62	4.47
ROA	5.20	4.96	5.03	5.08	5.10	5.09
CAN	3.14	3.20	2.97	2.56	2.40	2.11
USA	3.10	2.55	2.40	2.50	2.39	2.39
MEX	4.16	4.47	5.24	4.93	4.40	3.98
RNA	3.10	2.55	2.40	2.50	2.39	2.39
ARG	3.50	3.00	3.00	3.00	3.00	3.00
BRA	5.50	4.10	4.10	4.10	4.10	4.10
RSA	1.90	3.45	3.56	3.85	3.91	3.96
FRA	1.52	1.75	2.00	2.12	2.18	2.22
DEU	1.21	1.75	2.00	1.84	1.58	1.24
ITA	0.84	1.16	1.54	1.44	1.30	1.26
GBR	1.34	2.50	2.92	2.81	2.72	2.49
REU	0.62	1.70	2.20	2.38	2.38	2.31
ROE	1.21	1.97	2.17	2.29	2.31	2.29
RUS	4.00	3.29	3.70	4.09	4.45	5.01
FSU	3.24	4.01	5.12	5.24	5.95	4.84
TUR	5.20	3.40	3.60	3.75	4.00	4.00
RME	4.34	4.68	4.77	4.62	4.67	4.70
SA	2.59	3.65	3.98	4.44	4.48	4.50
RSA	5.61	6.50	5.99	5.80	5.59	5.36

Source: International Monetary Fund, World Economic Outlook Database, April 2010 (see http://www.imf.org/external/pubs/ft/weo/2010/01/weodata/index.aspx).

a Prior to 2010, our baseline incorporates historical GDP growth rates also from the International Monetary Fund. **b** These annual growth rates are converted to quarterly growth rates before being applied to the model.

5.2.7 Generating deviation results

In a dynamic model simulation of the effects of a pandemic, we run the model twice to create the baseline and policy runs. The baseline is intended to be a plausible forecast[8] while the policy run generates deviations away from the baseline caused by the pandemic. The baseline here incorporates independent region-specific forecasts for two macroeconomic variables: labour supply and real GDP (see Tables 5 and 6). Both of these variables are typically endogenous in a standard closure of the model. Therefore, to shock these variables in the baseline simulation equal to their independent forecast values, we must make them exogenous and we must make two other related macroeconomic variables endogenous. In this case, we endogenise population in

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

equation (6) above, and economy-wide Hicks-neutral technical change. These variables are allowed to adjust in the baseline run to accommodate the exogenous paths for labour supply and real GDP.

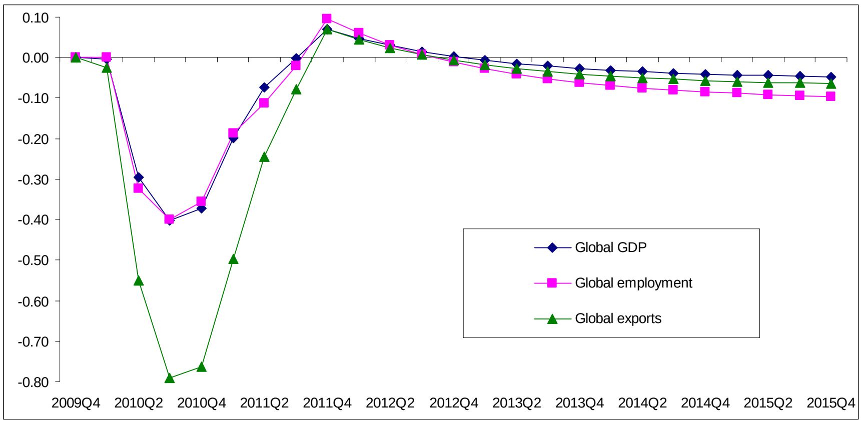
The policy simulation in our model is normally conducted with a different closure from that used in the baseline. In the policy run, real GDP must be endogenous: we want to know how it is affected by the shocks under consideration. Correspondingly, economy-wide technical change is exogenised and given the values it had in the baseline. More generally, all exogenous variables in the policy run have the values they had in the baseline with the exception of the variables of interest, e.g., labour supply, medical expenditures, tourism demands, etc. Comparison of results from the policy and baseline simulations then gives the effects of moving the variables of interest away from their baseline values. For the present study, the baseline and policy simulations differ with regard to the values given to exogenous variables representing an outbreak of pandemic influenza. We report the effects of the pandemic in terms of percentage deviations in the values of selected variables in the policy simulation away from their values in the baseline simulation.

6. The economic effects of pandemic influenza

6.1 Event 1: A high mortality-low infectiousness scenario

In Section 4.2 we explained that the direct effects of pandemic influenza are comprised of four sets of shocks: (i) a rise in demand for medical services; (ii) a decrease in hours worked per worker; (iii) deaths; and (iv) a decrease in international tourism. For Event 1, Figure 6 reports the quarterly effects on global employment and GDP of all four shocks combined. The annual impact on real GDP of Event 1 is reported in Table 7.

Figure 6. Effects of Event 1 on global employment, GDP and exports (percentage deviation from baseline)



The largest impacts occur in the event year, 2010 (Table 7): however, note that the annual impacts obscure the peak quarterly impacts (Figure 6). In quarter 1 of 2010 (2010:1) the event causes only small effects on GDP (-0.004%) and employment (0.001%); this reflects the slight dominance of the positive employment effects of increased medical expenditures over other negative effects in this quarter. In 2010:2, GDP and employment fall below baseline (-0.3% and -0.32%) as the negative effects of tourism reductions begin to dominate the medical expenditure effect. As infections begin to peak in 2010:3, so too do the negative effects on GDP and employment (-0.4%). Global economic activity begins to recover back to baseline from 2010:4 and this process takes until 2011:4.

Table 7 Effects of Event 1 on global and regional GDP (annual average percentage change)

Region	Year					
	2010	2011	2012	2013	2014	2015
World	-0.268	-0.051	0.024	-0.017	-0.036	-0.045
AUS	-0.242	-0.043	0.056	0.007	-0.017	-0.028
ROC	-0.226	-0.078	0.021	-0.012	-0.028	-0.037
CHN	-0.493	-0.082	0.095	0.035	0.001	-0.017
JPN	-0.281	-0.026	0.036	-0.009	-0.030	-0.039
KOR	-0.406	-0.087	0.056	-0.001	-0.032	-0.049
IND	0.019	-0.022	-0.023	-0.015	-0.012	-0.012
IDN	-0.172	-0.051	0.009	-0.011	-0.024	-0.034
SIN	-1.040	-0.222	0.211	0.063	-0.013	-0.052
ROA	0.158	-0.257	-0.152	-0.119	-0.102	-0.092
CAN	-0.308	-0.078	0.043	-0.010	-0.034	-0.045
USA	-0.217	-0.017	-0.019	-0.045	-0.057	-0.062
MEX	-0.080	-0.035	-0.011	-0.023	-0.030	-0.034
RNA	-0.099	-0.084	-0.080	-0.074	-0.070	-0.067
ARG	-0.365	-0.092	0.038	-0.029	-0.059	-0.072
BRA	-0.035	-0.055	-0.057	-0.056	-0.057	-0.058
RSA	-0.131	-0.044	0.011	-0.011	-0.024	-0.030
FRA	-0.360	-0.031	0.067	-0.004	-0.031	-0.042
DEU	-0.393	-0.040	0.079	0.004	-0.027	-0.041
ITA	-0.145	-0.092	-0.012	-0.026	-0.035	-0.040
GBR	-0.450	-0.033	0.085	-0.005	-0.038	-0.051
REU	-0.449	-0.095	0.079	0.002	-0.033	-0.050
ROE	-0.208	-0.100	0.010	-0.039	-0.058	-0.064
RUS	-0.059	-0.051	-0.009	-0.011	-0.020	-0.039
FSU	-0.223	-0.091	-0.002	-0.036	-0.053	-0.060
TUR	0.040	-0.060	-0.054	-0.046	-0.045	-0.045
RME	-0.079	-0.025	-0.017	-0.026	-0.029	-0.029
SA	-0.160	-0.049	0.019	-0.009	-0.024	-0.033
RSA	-0.213	-0.091	-0.008	-0.027	-0.035	-0.036

Our region-specific labour market closures allow for some short-run stickiness in real wages, followed by a movement towards long-run wage flexibility and a return of employment towards baseline (see Section 2.2.5 above). But while short-run wages are sticky, they are not rigid. Through 2010, with employment below baseline, region-specific real wages begin to fall relative to baseline, thus beginning the gradual process of returning the labour market to long-run equilibrium. This means by 2011:4, when the exogenous shocks describing the pandemic have been withdrawn, region-specific real wages are now below the level required to keep employment at its baseline level. This explains why in 2011:4 employment is above baseline. As 2011:4 employment is above baseline, so too is 2011:4 real GDP (Figure 6). This effect lasts until 2012:3, after which the effects of deaths on the total size of the population comes to dominate the long-run employment result (Figure 6). Note that the adverse effects on global trade (measured in terms of global export volumes) are twice those observed for employment and GDP.

Figure 7 shows the relative importance of each of the four sets of shocks in determining the overall employment outcomes. We see that reductions in labour supply (due to deaths), labour productivity (due to lost workdays) and the fall in international tourism have negative effects on aggregate employment in every year. Of these shocks, the fall in international tourism is the most important; the peak effect here is -0.52%. The reductions in labour productivity and labour supply are of less importance to the employment outcome in the short-run compared to other effects. Although the reductions in labour productivity and labour supply have a negligible employment impact once the pandemic ceases and wages have time to adjust, the reductions in labour supply do have a permanent effect on employment. The magnitude of the permanent labour supply effect is similar here to that observed in the annual results (-0.11%).

Figure 7. Effects of individual shocks of Event 1 on global employment (percentage deviation from baseline)

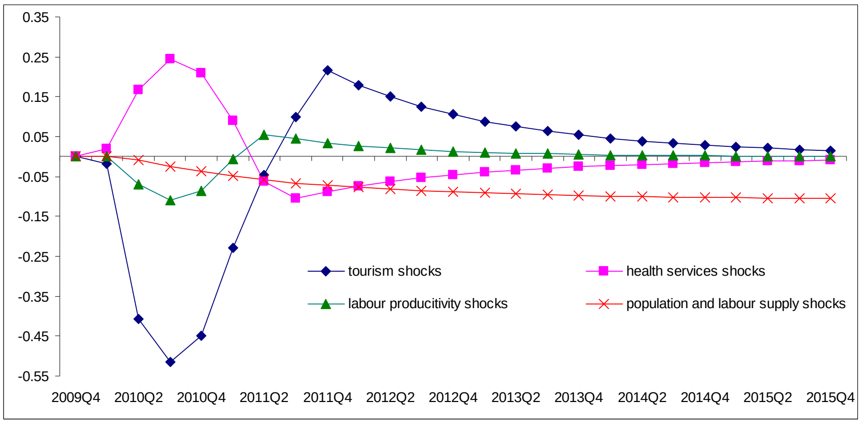
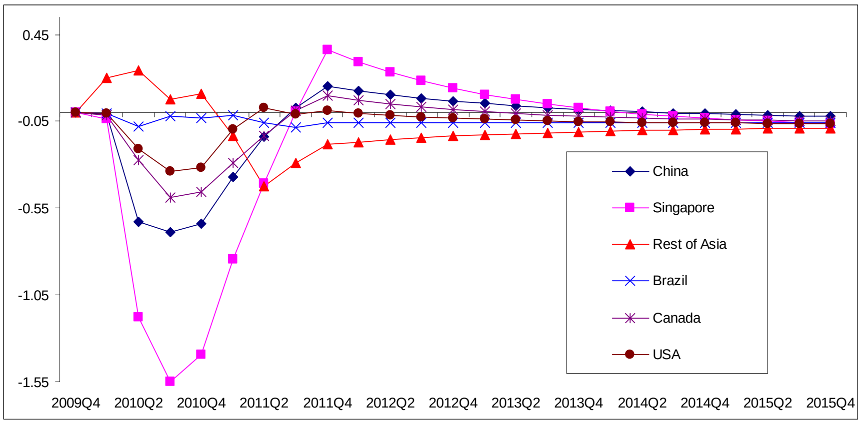


Figure 7 shows that, on its own, the movement in household spending towards medical services and away from other items of household expenditure generates a large positive deviation in employment in 2010; this peaks at 0.25% in 2010:3. The main reason for the positive deviation in employment is that the production of medical services is considerably more labour intensive than production of most other items of household expenditure. Note also in Figure 7 that the additional medical expenditures in 2010 have a negative effect on employment in 2011. This is a reflection of the wage mechanism outlined earlier: the positive employment deviation in 2010 associated with medical expenditures pushes up real wages, leaving them too high to maintain employment in 2011 when demand for medical services returns to its baseline level.

Underlying the global effects reported in Figure 6 are large variations in the regional effects of Event 1. Figure 8 presents Event 1 real GDP deviations for selected regions. Relative to the global real GDP outcome, the peak GDP impact is largest in Singapore at -1.55% in 2010:3. This result is almost entirely due to the negative effects on global trade in goods and services from the pandemic rather than the direct impacts on Singapore from the pandemic. Singapore is an entrepot port, through which large volumes of goods and services pass on the way to their final destination. This is reflected in export and import to GDP shares of around 150% in the base data. Thus, Singapore is strongly affected by the large fall in global trade relative to GDP (-0.8% versus -0.4%) due to its unique transit status. China also experiences large GDP deviations relative to the global result; the deviations peak at -0.69% in 2010:3. Like Singapore, the effects on China are mainly due to the reduction in global trade due to the pandemic. But the overall impact on China is smaller than for Singapore due to trade being less important for China's GDP than it is for Singapore (40% versus 150%).

Figure 8. Effects of Event 1 on GDP for selected regions
(percentage deviation from baseline)



Northern hemisphere industrialised countries experience rather small GDP deviations that peak at -0.5% (Canada) and -0.34% (USA) in 2010:3. In China, Canada and USA, the adverse effects of lost workdays and lost tourism dominate the (positive) short-run medical demand effect. This is not the case for the Rest of Asia region where the event is assumed to begin. Here, the adverse effects of lost workdays and lost tourism are dominated by the short-run medical demand effect. But the long-run negative effects from a smaller labour force for the Rest of Asia region are twice those observed globally. Brazil is an example of a region that experiences very minor GDP deviations relative to the global result due to relatively low pandemic impacts and low trade with the most affected regions (Asia). Regardless of the initial 2010 impacts, by 2011:4 real GDP for all regions (including those not presented in Figure 8) begin to converge to baseline. And by 2014:3 GDP in all regions moves below baseline due to the labour supply reductions (via deaths) that generate permanent long-run negative deviations in output.

6.2 Event 2: A low mortality-high infectiousness scenario

Figure 6 reports the combined quarterly effects of the Event 2 shocks on global employment and GDP; Table 8 reports the combined annual effects of the shocks on global and regional GDP. As with Event 1, the main impacts occur in 2010, the event year. Also, the pattern of effects over 2010:1–4 follows that seen for Event 1. In 2010, the global employment and GDP deviations peak at -6.4% and -4.5% below baseline in quarter 2. In comparison, the GDP deviation in Event 1 peaks in 2010:2 at -0.4%. Clearly, the peak economic effects of Event 2 are substantially larger than the peak effects of Event 1. As we shall see, this is due largely to the sharper contraction in global tourism under Event 2 relative to Event 1.

Figure 9. Effects of Event 2 on global employment, GDP and exports (percentage deviation from baseline)

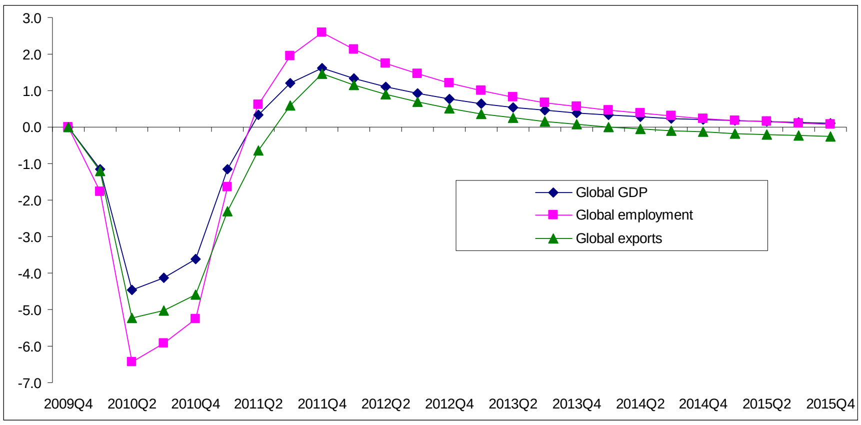


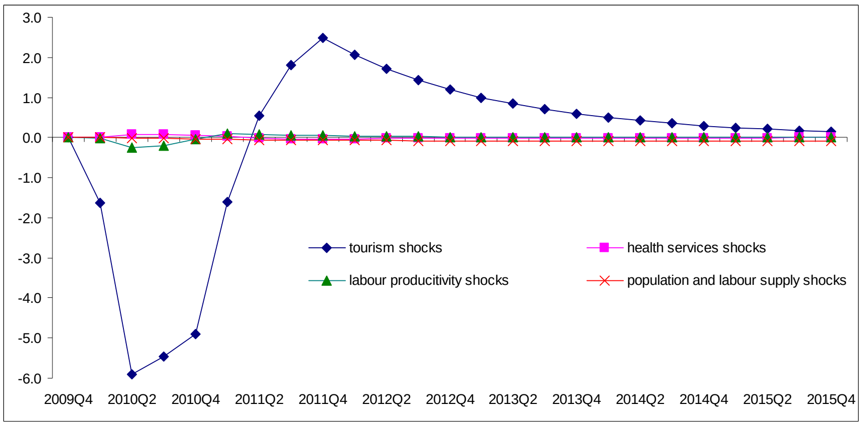
Table 8 Effects of Event 2 on global and regional GDP (annual average percentage change)

Region	Year					
	2010	2011	2012	2013	2014	2015
World	-3.342	0.489	1.024	0.501	0.256	0.135
AUS	-3.411	0.527	1.180	0.544	0.245	0.101
ROC	-3.302	0.325	1.051	0.503	0.219	0.066
CHN	-6.362	0.035	1.713	1.035	0.656	0.446
JPN	-2.948	0.642	0.999	0.475	0.229	0.110
KOR	-4.262	0.247	1.416	0.838	0.503	0.311
IND	-2.196	0.098	0.222	0.237	0.208	0.174
IDN	-2.083	0.116	0.738	0.578	0.452	0.357
SIN	-8.937	-0.705	2.372	1.125	0.532	0.245
ROA	-3.469	0.007	0.904	0.536	0.311	0.177
CAN	-4.124	0.483	1.189	0.480	0.150	-0.009
USA	-1.869	0.606	0.536	0.201	0.051	-0.021
MEX	-5.386	0.465	0.551	0.010	-0.324	-0.533
RNA	-0.056	-0.236	-0.300	-0.229	-0.183	-0.148
ARG	-5.437	0.483	1.670	0.664	0.230	0.042
BRA	-1.460	0.455	0.683	0.456	0.294	0.182
RSA	-2.315	0.424	0.849	0.494	0.291	0.176
FRA	-3.829	0.708	1.216	0.434	0.129	0.003
DEU	-4.032	0.538	1.256	0.498	0.181	0.042
ITA	-3.623	0.012	0.689	0.351	0.152	0.036
GBR	-4.526	0.760	1.403	0.463	0.119	-0.014
REU	-5.147	0.254	1.441	0.561	0.161	-0.026
ROE	-3.216	0.580	1.131	0.435	0.163	0.058
RUS	-1.332	-0.091	0.397	0.401	0.375	0.332
FSU	-2.572	0.181	0.835	0.429	0.210	0.089
TUR	-0.303	0.096	0.213	0.240	0.206	0.161
RME	-2.052	0.243	0.717	0.444	0.295	0.215
SA	-2.027	0.269	0.689	0.383	0.207	0.104
RSA	-3.843	0.024	0.779	0.403	0.211	0.114

With 2010 employment below baseline, real wages in 2010 begin to fall relative to baseline in order to gradually return labour markets to full employment. In 2011, when the epidemic-related shocks are steadily withdrawn, real wages are too low to keep employment at its baseline level. This accounts for the large transitory positive deviation in employment (and with it, real GDP) in 2011. Thereafter, the effects of pandemic-related deaths begin to dominate the employment and real GDP outcomes. As such, by 2015 we see employment (and hence real GDP) returning close to baseline.

Figure 10 indicates the relative importance of the different shocks in determining the overall employment effects. We see that reductions in labour supply and labour productivity have small negative effects on aggregate employment in 2010. As in Event 1, the dominant negative effect in 2010 is from lower international tourism, and the increased demand for health services has only a small positive effect on employment in 2010. But the relative importance of the tourism effect is much greater in Event 2, dominating the employment-promoting effects of higher health spending. From 2011, the employment effects of all the pandemic shocks (bar deaths) are gradually eroded via wage adjustment. The exception, deaths, generates small permanent reductions in labour supply and thus employment.

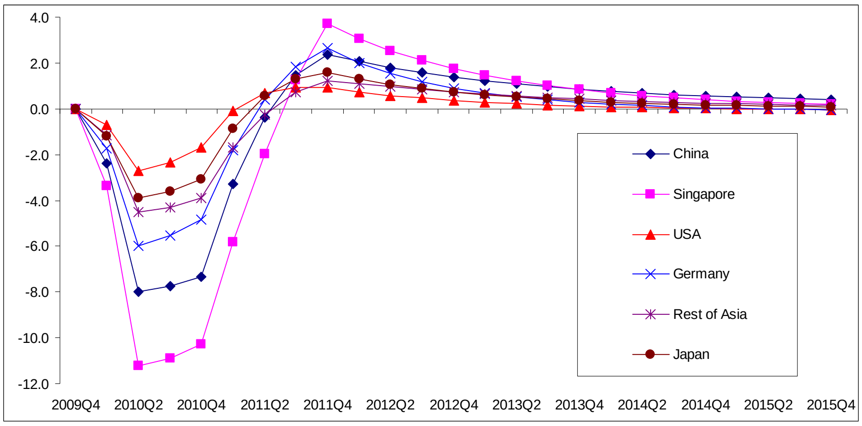
Figure 10. Effects of individual shocks of Event 2 on global employment (percentage deviation from baseline)



As already mentioned, compared to Event 1, lower international tourism dwarfs all other effects in Event 2. Event 2 has a much higher global infection rate than Event 1: 24% versus 2% (see Figure 3). The infection rate is the dominant determinant of the size of the tourism effect in each event. Because the pandemic is assumed to be more virulent in Event 1, the distribution of infections in Event 1 is heavily skewed towards serious (and thus expensive) cases (e.g., hospitalisations, deaths) compared to Event 2. The net effect of these assumptions is that the medical demand, labour productivity and labour supply effects are of about equal size in Event 1 and Event 2. Thus, much larger tourism effects in Event 2 mean that the relative importance of other effects is much smaller than in Event 1.

Figure 11 presents Event 2 GDP deviations for selected regions. In contrast to Event 1, all regions are projected to experience lower output in the short run under Event 2. Singapore experiences the largest negative deviation in 2010 real GDP (-11.2%). This reflects large falls in exports in 2010, arising primarily from a reduction in international tourism. As discussed earlier, trade is a very high share of Singapore's GDP (≈150%), and as such, it is the region most exposed to the contraction in 2010 global trade. China is also projected to experience much lower output under Event 2, but this only peaks at 8% as the Chinese economy is less dependent than Singapore on trade. Relative to Event 1, industrialised regions are expected to experience larger negative effects on output, mainly due to the importance of tourism in their economies (e.g., Germany, Japan and USA). From 2011 onwards, GDP in most regions slowly moves toward baseline, eventually converging on or below baseline, due to the lasting effects of labour supply reductions from pandemic-related deaths.

Figure 11. Effects of Event 2 on GDP for selected regions (percentage deviation from baseline)



6.3 Sensitivity analysis: exploring the effects of post-pandemic wage adjustment

An interesting feature of the results for Event 2 is the strong rebound in employment that is observed once the pandemic ends. For instance, we see from Figure 9 that global employment rises to 2.6% above baseline by 2011:4. The strength of the post-pandemic employment rebound hinges on our assumptions about the speed with which wages adjust in the post-event recovery phase. While in part this will depend on region-specific institutional details relating to wage bargaining, empirical evidence suggests that real wages tend to be stickier downwards (i.e., during a recession) than they are upwards (i.e., during an expansion). We therefore conduct sensitivity analysis with respect to this response by adopting the asymmetric sticky wage function outlined in Section 2.2.5. This makes real wages more responsive upwards during the recovery phase of the pandemic relative to their behaviour under the standard wage setting equation employed in the simulations discussed in Sections 3.1 and 3.2.

Figure 12 shows the quarterly effects of Event 2 on global variables assuming an asymmetric sticky wage response. The main impacts still occur in 2010, the event year, but once the pandemic ends the employment rebound are much smaller: 0.5% in 2011:3 versus 2.6% in 2011:4. Because of this, global employment returns close to baseline by 2012:2 (0.1%) whereas under symmetric wage adjustment (as assumed in Section 3.2 above) it takes until 2015:3 to achieve the equivalent employment deviation from baseline. We believe that this smaller post-pandemic employment rebound is likely to be a more plausible description of the post-pandemic phase of Event 2, particularly given the deep troughs in indicators of economic activity generated during the pandemic phase of the event.

Figure 12. Effects of Event 2 on global employment, GDP and exports assuming asymmetric real wage response (percentage deviation from baseline)

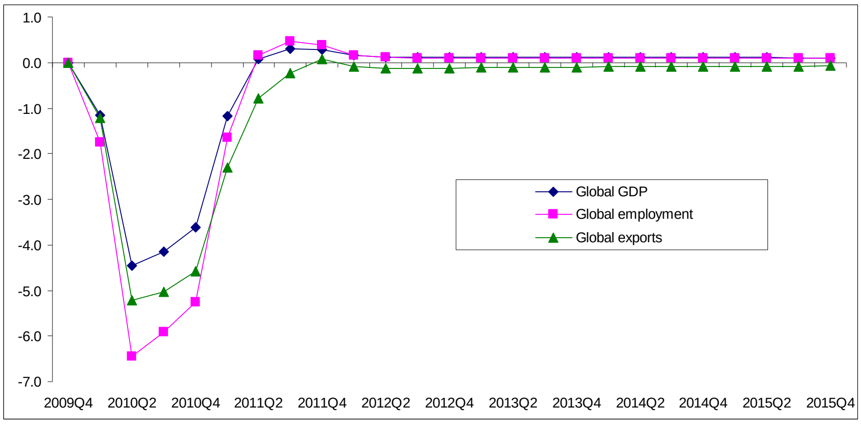
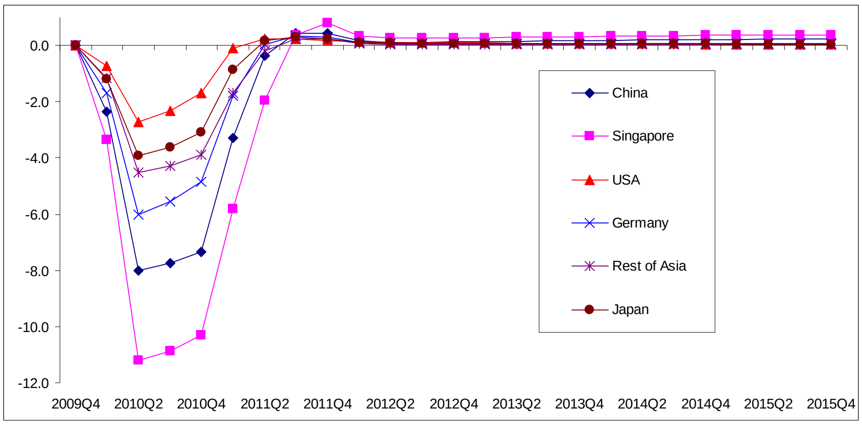


Figure 13 presents the Event 2 GDP deviations for selected regions assuming an asymmetric sticky wage function. All regions experience the same negative GDP effects from Event 2 during the pandemic. In contrast to our previous Event 2 results, when GDP in most regions slowly starts to move toward baseline from 2011:2 onwards, the size of the GDP rebound is much smaller. For instance, the size of the GDP rebound is now only 0.8% for Singapore rather than 3.7%; for China it is now 0.4% rather than 2.4%. Thus, for most regions, the recovery of GDP to its baseline values is now delayed to around 2012.

Figure 13. Effects of Event 2 on GDP for selected regions assuming asymmetric real wage response (percentage deviation from baseline)



7. Concluding remarks

We have modelled on a quarterly basis two pandemic influenza scenarios constructed using the commonly-used epidemiological approach known as the Susceptible-Infected-Recovered model. We apply the shocks for each scenario on a quarterly basis so that the timing of the infections in each region closely match the dynamics of new infections. The timing of the pandemic cycles varies by continent and hemisphere. Quarterly shocks capture these timing differences and the trade-related inter-regional "ricochet effects" across regional economies that they imply. Quarterly results show regional economies being affected not only directly by the epidemic within their own region, but also indirectly via trade effects with other regions affected by the pandemic at different stages of the event's global transmission. Related to this, the size of the reductions in international tourism of any pandemic will determine the size of the global effects, all other things being equal.

The results also make clear that regions with greater economic integration to the world economy (via international trade) tend to be more greatly affected by the pandemic events, all else being constant. The two scenarios give quantitatively and qualitatively different results. This is a function of the nature of each scenario as currently modelled. Different combinations of infection and virulence rates will give different results from those modelled here; Event 1 has high virulence but low infection rates whereas Event 2 has low virulence but high infection rates. Given this foregoing qualification, our experience in previous work of this kind (see Dixon et al. 2010; Verikios et al. 2010) we feel that the nature of the two events cover a broad spectrum of possible pandemic events. As such, these results provide policy makers with useful information on the orders of magnitude of the global economic effects of future pandemics.

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