Economic Modeling of SARS: The G-Cubed Approach[*]

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1. Overview

Despite the catastrophic and wide spread consequences of infectious diseases such as malaria and HIV/AIDS, the impact of epidemics and pandemics has been considerably under-researched in economics[1]. According to UNAIDS (the Joint United Nations Programme on HIV/AIDS), at present 42 million people globally live with HIV/AIDS. The HIV/AIDS disease is estimated to claim 3.1 million lives in 2002. Malaria kills more than one million people a year. Earlier outbreaks of infectious diseases have been equally devastating. In 10 months during the outbreak of the Spanish Flu in 1918-19 at least 40 million people died worldwide. In comparison, the number of probable cases of SARS (Severe Acute Respiratory Syndrome) reached 8,437 worldwide by July 2003, with a death toll of 813. Yet SARS has captured world attention because it caused significant disruption and economic loss to the world economy. Lee and McKibbin (2004) estimate that SARS reduced world wide GDP by $40 billion dollars in 2003[2]. Given the experience with SARS, it is probable that an outbreak of a Spanish flu size pandemic in the world today would be devastating to the world economy. Yet in purely economic terms there appears to be a big gap between the investment in preventing the emergence of these pandemics and the expected costs to the global economy.

Before the SARS outbreak most economic studies of the cost of disease focused on the long run economic growth impacts of disease in the context of standard models of economic growth[3]. Since the SARS outbreak a new approach to analyzing the macroeconomic costs of diseases has emerged which suggest that the short run cost of major disease outbreaks is significant.

This paper proposes a methodology aimed at getting a better estimate of the cost of infectious diseases both in real time as a disease emerges as well as in the long term. In the short term the availability of a way to analyze the cost of disease will enable a better

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1 Exceptions can be found in the Commission on Macroeconomics and Health (2001). Other papers in an emerging empirical literature include Bloom Canning and Sevilla (1997), Bloom and Mahal (2001), Brainerd and Siegler (2002), Haacker (2002) and Sachs and Malaney (2002). See also Gersovitz and Hammer (2004) for a theoretical analysis of optimal disease response.
2 A number of other studies of the economic costs of SARS have also been done such as Australian Treasury (2003), Chou, Kuo and Peng (2004), Fan (2003), Hanna and Huang (2004) and Wen et al (2004).
3 See Barro and Sali-Martin (1995) for the growth framework and the empirical references in footnote 1 for the approaches.

allocation of financial resources that should be devoted to responding directly to the outbreak of disease. In the longer term there is a strong case for greater investment in public health systems and response measures to minimize the probability of outbreaks. Section 2 sets out the methodology used in Lee and McKibbin (2003) for evaluating the cost of SARS. This section analyzes what was done to the G-Cubed model as well as the information requirements in order to estimate the impact of SARS. Section 3 explores how this approach might be generalized to explore the outbreak of a range of infectious diseases and what information and methodological improvements could be made to enhance the original research. One of the key aspects of the outbreak of an infectious disease is the uncertainty about the evolution of the disease and the possible impacts on economic activity. One way to deal with this is to use scenario analysis to create a broad range of possible outcomes and use these with updating probabilities to calculate expected losses. In this way, responses can evolve as new information is revealed. The ability to use scenario analysis on economic models is a great strength of a model based approach. This section also considers model developments that would improve the predictive ability of the G-Cubed model, including the need for flexible disaggregation of countries and sectors of the economy depending on the nature of the disease under consideration. Section 4 moves beyond the short term evaluation of health emergencies and explores how the approach outlined in this paper might be used to calculate the longer term cost of disease and therefore provide a measure of the return to investment in public health systems so that more relevant cost benefit calculations can be undertaken when designing national and international investments in health expenditure. A summary and directions for future research are presented in section 5.

2. The G-Cubed approach to Modeling SARS

a. The G-Cubed Model

One of the key aspects of the SARS outbreak was the way markets for goods and services as well as financial markets responded to the news of the outbreak as well as to the flow of information on a daily basis. In modeling the impact of infectious diseases, the response of individuals in these various markets is critical. The direct impact on markets within economies also resulted in economic outcomes that reverberated within economies and across national borders. To capture this it was important to use a model that incorporated

the key affected countries as well as having sectoral disaggregation and incorporated the impact on financial markets and how this affected other markets. The G-Cubed (Asia Pacific) model, based on the theoretical structure of the G-Cubed model outlined in McKibbin and Wilcoxen (1999), was ideal for such analysis having both detailed country coverage of the region and rich links between countries through goods and asset markets. [4] A number of studies—summarized in McKibbin and Vines (2000)—show that the G-cubed model has been useful in assessing a range of issues across a number of countries since the mid-1980s.[5] A summary of the model coverage is presented in Table 1. Some of the principal features of the model are as follows:

● The model is based on explicit *intertemporal* optimization by the agents (consumers and firms) in each economy[6]. In contrast to static CGE models, time and dynamics are of fundamental importance in the G-Cubed model.

● In order to track the macro time series, however, the behavior of agents is modified to allow for short run deviations from optimal behavior either due to myopia or to restrictions on the ability of households and firms to borrow at the risk free bond rate on government debt. For both households and firms, deviations from intertemporal optimizing behavior take the form of rules of thumb, which are consistent with an optimizing agent that does not update predictions based on new information about future events. These rules of thumb are chosen to generate the same steady state behavior as optimizing agents so that in the long run there is only a single intertemporal optimizing equilibrium of the model. In the short run, actual behavior is assumed to be a weighted average of the optimizing and the rule of thumb assumptions. Thus aggregate consumption is a weighted average of consumption based on wealth (current asset valuation and expected future after tax labor income) and consumption based on current disposable income. Similarly, aggregate investment is a weighted average of investment based on Tobin's q (a market valuation of the expected future change in the marginal product of capital relative to the cost) and investment based on a backward looking version of Q.

● There is an explicit treatment of the holding of financial assets, including money. Money

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is introduced into the model through a restriction that households require money to purchase goods.

● The model also allows for short run nominal wage rigidity (by different degrees in different countries) and therefore allows for significant periods of unemployment depending on the labor market institutions in each country. This assumption, when taken together with the explicit role for money, is what gives the model its "macroeconomic" characteristics. (Here again the model's assumptions differ from the standard market clearing assumption in most CGE models.)

● The model distinguishes between the stickiness of physical capital within sectors and within countries and the flexibility of financial capital, which immediately flows to where expected returns are highest. This important distinction leads to a critical difference between the *quantity of physical capital* that is available at any time to produce goods and services, and the *valuation of that capital* as a result of decisions about the allocation of financial capital.

As a result of this structure, the G-Cubed model contains rich dynamic behavior, driven on the one hand by asset accumulation and, on the other by wage adjustment to a neoclassical steady state. It embodies a wide range of assumptions about individual behavior and empirical regularities in a general equilibrium framework. The interdependencies are solved out using a computer algorithm that solves for the rational expectations equilibrium of the global economy. It is important to stress that the term 'general equilibrium' is used to signify that as many interactions as possible are captured, not that all economies are in a full market clearing equilibrium at each point in time. Although it is assumed that market forces eventually drive the world economy to a neoclassical steady state growth equilibrium, unemployment does emerge for long periods due to wage stickiness, to an extent that differs between countries due to differences in labor market institutions.

b. **How SARS was incorporated into the model**

The approach taken in the G-Cubed model can be broken down into several steps. We first examined the initially affected economies of China and Hong Kong to isolate key features of the shocks in these economies. We then identified how these shocks could be

modeled in the framework of the G-Cubed model and how these shocks might evolve over time within China and Hong Kong. Given the direct shocks we then calculated how the disease might spread to other economies globally.

The emergence of an infectious disease would be expected to have a wide range of impacts. In the long run the outbreak could change health expenditures which would impact of government fiscal positions as well as household budgets. It could impact on the amount and nature of human capital formation through the death of vulnerable people. We decided that in the SARS case these longer terms effects were ambiguous in their effect. For example, although initial spending on SARS would likely raise health spending, the death of highly vulnerable people such as those with HIV/Aids might lower longer run health spending. Thus we decided to focus on the short run impacts. For other disease outbreaks, the longer run impacts might be important to incorporate. This will be discussed in the next section.

In the short run, the outbreak of an infectious disease can lead to dramatic changes in demand through changes in peoples spending patterns. This was an important aspect of SARS. Entire populations, rather than just those people who contracted SARS, changed their behaviour significantly, both within effected economies and in other countries that had no disease outbreak. Demand for goods and services associated with public interactions were directly affected. In industries such as tourism, restaurants, air travel, hotels etc consumption demand fell significantly. As well as shocks to the demand for particular products, there were falls in overall levels of spending. There were also impacts of the costs of undertaking business as greater screening was introduced in affected economies. In addition to the direct costs to firms and households, the financial markets were impacted. There were falls in asset prices due to the direct effect of lower future profitability of industries in the affected economies, as well as a risk premium due to the increased uncertainty about the possible evolution of the disease. The movements of prices in financial markets directly impacted on domestic and foreign investment decisions. In the case of SARS these effects dissipated relatively quickly as it became clear that authorities were responding to the outbreak and reported outbreaks began to subside. If the risk premia has stayed for longer there could well have been significant impacts on future potential production through lower investment. This was considered in the modeling through changing the assumption about expectations of the persistence of the outbreak.

In summary we modeled the direct impact of SARS in China and Hong Kong through:

- fall in demand for goods and services from directly affected sectors
- fall in overall demand for goods
- rise in the cost of producing goods and services in directly affected sectors
- rise in the country risk premium

We estimated the magnitudes of each of these shocks from data collected by official agencies as well as from banks and financial analysts who were monitoring the situation in Hong Kong and China. The actual shocks used in our study were

- Sector-specific demand shock to retail sales sector: 15% drop of demand for the exposed industries in the service sector with no additional spending on other goods;
- Increase in costs in the exposed activities in the service sector of 5%.
- Increase in country risk premium: 200 basis point;

One of the problems was how disaggregated we could model the precise shocks. For example in the G-Cubed model we have an aggregate service sector yet the shocks themselves were very sector specific within the service industries. One option would be to disaggregate the model to allow more precise evaluation. This is an option discussed in the following section. Given the time constraint, we used information on the sectoral composition of the economies to disaggregate the shocks outside the model using detailed data from the Global Trade Analysis Project (GTAP) model and weighted each shock with the sectoral share. This weighting was called the "sectoral exposure to SARS". This index was assumed to be proportional to the share of SARS affected industries within the service sector. Industries like tourism, retail trade, airline travel etc were impacted severely. The GTAP5 database was used to calculate the share of exposed sectors to total services for each country. The exposed sectors were based on GTAP definitions of wholesale and retail trade, and hotels and restaurants (TRD), land transport (OTP) and air transport (ATP). The "index of sectoral exposure to SARS" is shown in Figure 1. This index is applied to the sector-specific shocks that were developed for the Chinese economy.

The next issue was to decide how to apply the shock in China and Hong Kong to other countries. The economic shocks would be transmitted by the flows of goods and capital

between economies but we needed to include the possibility that SARS would also appear in other economies. Without a model of epidemics or contagion we developed a simple index to measure the likelihood that the SARS would be transmitted to other economies. The transmission of SARS, as distinct from the economic transmission through global markets would likely depend on a number of factors. We referred to this as the index of the "global exposure to SARS". The speed of spread was assumed to be likely to depend on (i) tourist flows (ii) geographical distance to China (and Hong Kong), (iii) health expenditures and sanitary conditions, (iv) government response, (v) climate, (vi) per capita income, (vii) population density, and so on. Table 2 presents indicators on health expenditures, tourist arrivals and sanity conditions for selected countries. There are more than 33 million annual visitors to China. Hong Kong has annual tourist arrivals that are over 200 % of the local population. Overall health expenditure as a ratio to GDP is not small in Asian countries but health expenditure per capita is only $45 in China.

With more data we could have done some econometric estimation to capture these influences. Lacking that data, for the purposes of the paper we constructed a rough measure of the intensity of exposures to SARS, based on the above information and the number of cumulated cases of SARS for each country. It would have been extremely helpful to have collaborated with experts in disease transmission to get a better estimate of the likely international transmission of SARS.

The index of "global exposure to SARS" is contained in Figure 2. This was used to scale the shocks in China and Hong Long to other countries. It was applied to each shock. For example it was used to scale the country risk shocks calculated for all other countries. If a country had a global exposure index of 0.5, the country risk premium shock will be the Chinese shock of 2% adjusted by the "global exposure to SARS" index which gives a shock of 1%. For the shocks to costs in the service sectors we use the basic shock multiplied by the "sectoral exposure to SARS" multiplied by the "global exposure to SARS" to get the final shock to services in each country.

Using these basic shocks we then considered two out of a wide variety of possible scenarios. The first was that the shocks lasted for one year (subsequently scaled to six months in the final study) and the second that the shocks were much more persistent. This persistence could reflect either a recurrence of SARS in future years but with less severity that 2003, or

the emergence of a new disease each year. The expectations about the future emergence of a disease led to much larger losses in 2003 as well as larger losses over time. In the paper we considered both the GDP losses for each country and the dynamic story of adjustment over time.

Table 3 contains results for the percentage change in GDP in 2003 as a result of the temporary and permanent SARS shocks as well as the contribution of each component (i.e. demand decline for services, cost increase for services and country risk premium).

Focusing on the GDP results it is clear that there are interesting differences between the various components of the overall shock as well as between the temporary and permanent shocks. The temporary shock has its largest impact on China and Hong Kong as expected. The loss to Hong Kong of 2.63% of GDP is however much larger than that of 1.05% for China. This primarily reflects the larger role of the service sector in Hong Kong, the larger share of impacted industries within the service sector in Hong Kong and the greater reliance on trade within the region of Hong Kong. Taiwan is next most affected losing 0.49% of GDP in 2003 followed closely by Singapore with a loss of 0.47% of GDP.

The calculations when expressed as a percent of each country's GDP may appear to be small. However when translated into an absolute dollar amount, these figures imply that the global economic loss from SARS in the case were the disease was expected to be temporary is close to $US40 billion in 2003.

For Hong Kong the increase in costs in the service sector is by far the largest contributing factor to the loss of GDP. In China it is evenly spread across the three factors. The temporary increase in the country risk premium of a 200 basis point is estimated to lower GDP by 0.33% for China and by 0.20% for Hong Kong. Interestingly, the risk premium shock has very negligible impacts, of less than 0.01% of GDP, on the other countries such as Taiwan and Singapore which adopt floating exchange rate regimes although they are also subject to a substantial rise in the country risk premium by 150 and 100 basis point respectively. The difference comes from the fact that exchange rate depreciation helps Taiwan and Singapore to avoid a rise in real interest rate and subsequent output decline. The persistent SARS shock is also much more serious for Hong Kong and China. The primary impact is from the persistence in the rise of the country risk premium. Although the same in

2003 as for the temporary shock, the persistence of the country risk premium causes are much larger capital outflow from China and Hong Kong. This impacts on short run aggregate demand through a sharp contraction in investment and a persistent loss in production capacity through a resulting decline in the growth of the capital stock which reduces the desirability of investment. The extent of capital outflow will be discussed below.

Interestingly, the difference in GDP loss in 2003 when SARS is expected to be more persistent distinguishes between two groups of countries. China, Hong Kong, Malaysia, Philippines, Singapore, Taiwan experience a larger loss in 2003 when SARS is expected to be more persistent, whereas the OECD economies and others experience a lower GDP loss. This reflects the greater capital outflow from the most affected countries into the least affected countries which tend to lower the GDP of those countries losing capital and raises the GDP of those countries receiving capital. The countries in the first group that are less affected by SARS nonetheless are worse off with a more persistent disease because of their trade links with Hong Kong, China and Singapore.

The results for GDP illustrate how the costs of SARS can be very different in 2003 depending on expectations of how the disease will unfold. It is also interesting to examine the change in economic impacts over time.

The dynamics of adjustment are contained in Figures 3 through 5. We present three sets of figures containing 6 charts within each figure. These results are all expressed as deviation from the underlying baseline of the model projections. They show how key variables change relative to what would have been the case without SARS. Figures 3 and 4 give results down the left column for the results of the temporary SARS shock and down the right for the results of the more persistent SARS shock. This enables a comparison between the two for the impacts on the real economy and trade flows. Figure 6 gives more detailed financial outcome for the persistent SARS shock.

Figure 3 contains results for real GDP, investment and exports for both the temporary and persistent SARS shock. The loss in GDP from the temporary shock is largely confined to 2003. The persistent shock not only has a larger impact on GDP in 2003 because of expectations about future developments, but it has a persistent impact on real GDP for a number of years. Investment falls more sharply in 2003, which is the source of the larger

GDP loss.

The results for exports are interesting. In the case of the temporary shock, exports from Hong Kong fall sharply. Yet, in the more persistent case, exports from Hong Kong rise in 2003. The reason for this difference is that the more persistent the shock, the larger the capital outflow from affected economies. A capital outflow will be reflected in a current account surplus and a trade balance surplus. For this to occur either exports must rise or imports fall or both. This can be seen clearly in Figure 4.

In the case of the temporary SARS shock the net capital outflow from China and Hong Kong (relative to base) is around 0.3% of GDP. However, when the shock is more persistent this capital outflow (top left panel) rises sharply to 1.4% of GDP for Hong Kong and 0.8% of GDP for China. This capital outflow is reflected in the trade balance surplus in both. This shift in the trade balance is achieved by the capital outflow depreciating the real exchange rate of both China and Hong Kong substantially.

We see in Figure 5 that both Korea and Singapore experience nominal exchange rate depreciations which limit the extent of price declines in those economies even though China is experiencing falling prices.

We also see in figure 5 that the problems in the service industries in China and Hong Kong are reflected in the share market valuations in the manufacturing sectors in these economies (lower right hand chart summarized in Tobin's Q). The SARS outbreak is predicted to have widespread economic impacts beyond the decline in the most affected service industries.

Using the G-Cubed model to explore the impact of SARS gave some important insights into the nature and size of potential costs of a disease like SARS. The study was undertaken without any prior analysis in this area to work from. The following section will explore how the approach could be improved and extended.

3. Generalizing the G-Cubed approach for short run analysis of a range of outbreaks

The approach taken in the study of SARS that used the G-Cubed model has been outlined in section 2. It is clear that the way the shocks were implemented depended very much on the particular characteristics of SARS and the time frame for analysis, however there are a number of ways that this approach could be generalized and implemented for a range of diseases. The main issues considered in this section are divided into: model development; incorporating epidemiological data and models; and use of scenario analysis to explore possible outcomes in a probabilistic approach.

a. Model Development Issues

The first issue that requires great flexibility is a better way to assess the sectoral impact and country impacts of particular diseases. In the case of SARS we already had a model (the Asia Pacific version of G-Cubed) with country coverage for the main affected countries in some details (except Canada which has subsequently been added to the model). We need to be able to have a wide range of countries or a way of generating models with the appropriate country coverage for the specific disease outbreak. We have developed a technique for generating version of the G-Cubed model for specific aggregations. The biggest drawback currently is that we are limited by the data availability at the detailed sectoral level to those data that are available in the GTAP database. We also require aggregate data for particular countries which are currently available from the OECD, World Bank and International Monetary Fund. For many countries especially in the developing world, there is a severe problem with good, consistent and timely data

If the problem of the appropriate country coverage for a particular disease outbreak can be solved, we then need to develop a better way of modeling the sectoral impacts. Once the key impacted sectors are identified, a first step would be to develop an index of the sectoral exposure to the disease, as was done for the SARS study. This would enable an existing version of the G-Cubed model to be solved to quickly produce an initial estimate of the likely effects. However, it would also be useful to develop a method to quickly disaggregate the sectoral coverage of the model to deal with greater detail when required. This way a more precise estimate of impact could be found. For example in the case of Avian Flu, it would be preferable to have greater detail on agriculture sectors in order to capture the specific impacts of flocks culling and changes in consumption expenditure on chicken and related goods consumption. This is feasible within the G-Cubed framework. The key issue is the estimation of the detailed elasticities across production and consumption decisions.

Together with the co-developer of the G-Cubed model Professor peter Wilcoxen, we have developed a technique for alternative aggregation of the G-Cubed databases from highly disaggregated data and also to undertake the estimation of key parameters at more detailed levels (currently possible at 35 sectors using the Jorgenson-Wilcoxen dataset for the United States).

Other important longer term model development issues include the introduction of greater detail on the health expenditures within national budgets in the model. It might also be important to incorporate the impact of various diseases into the human capital stock.

b. Incorporating Epidemiological data

One of the most important aspects of modeling the economic impacts of disease in real time is the use of projections and data from models of disease propogation[7]. In our original SARS study we used a very rough measure of disease propagation based on economic characteristics. Clearly input from experts on likely paths of a disease would be superior. A outlined by Edmunds and Gay (2004) the key information that would be need are answers to a variety of questions: how infectious is the disease; what is the potential for epidemic; what is the potential for a pandemic; what are the routes of transmission; what are the likely outcomes of infections; what treatments are available; what control measures are effective; how many infections and deaths are likely; can the transmission chains be broken?.

Each of these answers will likely be known with a great deal of uncertainty and therefore the number of alternative scenarios that could be run within an economic model are very large.

c. Use of Scenario Analysis

One of the strength of using a consistent framework such as an economic model is that assumptions can be changed and the implications assessed. As outlined in the previous section, in the case of emerging infectious diseases there are a wide range of possible directions that a disease can take. One option for the use of the G-Cubed model would be to generate a wide range of options for the propagation of the disease and the shocks hitting

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7 For example Edmunds and Gay (2004)

economies. In principle, these assumptions could be given probabilities so that a distribution could be developed for the expected cost of a disease. Various intervention measures could be modeled and the impact of these on the distribution could be assessed in order to get a measure of the expected benefits of intervention whether defined as medical intervention, public information programs, quarantine responses or other methods for affecting the course of a disease.

As the disease evolves the distribution could be modified with new shocks introduced and probabilities modified. This approach could also be a useful way to judge the most suitable forms of intervention as well as encouraging countries to respond so as to avoid excessive economic costs locally or globally.

An example is helpful. Suppose that in the case of SARS we are able to develop 5 different scenarios about the spread of the disease and various response measures. Each of these scenarios would be transformed into shocks and the G-Cubed model solved under each scenario. Suppose that the range of GDP losses under each scenario were found to be 0.2%, 0.4%, 0.6%, 0.8% and 1% of GDP. Suppose subjective probabilities assigned to each outcome were 50% 20% 15%, 10% and 5%. The expected loss in GDP would be 0.4% of GDP. This figure could be continually updated as new scenarios emerged and older scenarios are re-evaluated. The various intervention strategies could also be modeled this way to get a better measure of potential costs and benefits and alternatives. Another illustration is given in figure 6 where 54 different scenarios are developed for a pandemic each with a probability. The model can be used to generate the outcomes of a wide range of global, country specific and sector specific distributions of losses. Figure 6 show the GNP loss on the horizontal axis and probability on the vertical axis. By doing a stochastic analysis it would in principle be possible to generate a distribution of costs across a range of intervention strategies and derive the best intervention where the expected marginal cost is equal to the expected marginal benefit. In practice it is likely that authorities would want to use the distribution of outcomes to evaluate how the disease is likely to unfold over time rather than undertaking the explicit optimization.

One of the key aspects of successful intervention is likely to be disclosure of the disease outbreak by national governments to the WHO. Scenarios with disclosure and without disclosure could be developed at the early onset of outbreaks to demonstrate to countries in the midst of a epidemic that it is economically in their interest to disclose the disease outbreak. Before pandemics begin it would be possible to use the same methodology

to develop hypothetical scenarios around historical episodes to test whether revelation of the disease would lead to higher or lower costs for individual countries.

4. Generating longer term estimates of the benefits of avoiding major outbreaks using counterfactual scenarios

One of the key features of the approach taken in the G-Cubed model is the ability to evaluate the short term impacts of a disease outbreak as well as the ability to evaluate the longer term implications of the disease. This implies a capability to evaluate the cost of disease in a general equilibrium sense rather than only calculating the cost of medical services for treating those directly contracting the disease. This implies that the model could be used to explore the return to investment in a variety of disease prevention and response measures of a longer term nature so that a more reasonable cost benefit analysis of investments in public health systems, responses to outbreaks and research into long term treatment of diseases could be explored.

The calculation of costs avoided would need to rely on the use of the type of scenario analysis outlined above with probabilities applied to various scenarios to explore expected costs of outbreaks. The integration of epidemiological models is crucial inputs into the likely propagation of diseases and the likely impact of measures on changing disease outcomes. Clearly the outbreak of SARS has shown how costly an infectious disease can be in a short time and how widespread the costs can be globally. Although to my knowledge a study hasn't been undertaken yet of the costs of intervention in the case of SARS relative to the benefits of preventing a major pandemic. My guess is that if such as study was to be done it would show that the potential costs avoided by containing SARS by the measures implemented in 2003 far outweigh the costs of policy interventions such as screening, public information, quarantine etc.

5. Summary and possible research directions

This paper has outlined the approach taken by Lee and McKibbin (2004) using the G-Cubed multi-country model to evaluate the economic implications of the SARS outbreak of 2003. It has also outlined how the approach could be improved with better information in the model and better integration with the epidemiological models of disease propagation. The

paper has also considered how the approach could be modified to deal quickly with a wide range of diseases and used for evaluation of alternative intervention strategies using stochastic methods to generate a distribution of possible outcomes across a range of scenarios from epidemiological models.

Finally the paper has briefly considered how the same economic framework could be used to not only evaluation the short term costs of a major pandemic as it emerged, but also to form a basis for applying to an evaluation of the long term benefits of investment in a wide range of disease prevention and control strategies, in particular investments in public health systems. A clear lesson from the SARS outbreak is that the costs of future disease outbreaks are likely to be large and not just related to the costs of treating individual patients but have more widely felt economic consequences because of the response of industry and individuals to disease outbreaks.

One of the key lessons from the research undertaken so far is that we are a distance from having a complete framework that can easily be brought to bear on the key question of the short term costs of disease. There will need to be substantial investment in developing the technology that will enable better evaluation of the issues laid out this paper. There needs to be improved availability of data and research into the interaction of health and economic behaviour in the models that we already have. There needs to be greater interaction between economic modelers and epidemiological modelers to better understand and evaluate the likely consequences of pandemics and epidemics. One of the positive outcomes of the SARS outbreak is that these groups of researchers have been brought together and are now developing ways to improve the evaluation of the short term and long term costs of disease. This clarification of the likely costs of disease will perhaps encourage governments to invest far more in disease prevention and management than has been undertaken to date. This is likely to be particularly important in the improvement of health systems in developing countries since SARS has demonstrated as have pandemics before, that in a integrated world, the outbreak of infectious diseases are not only a problem for the originating country.

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Table 1: The G-Cubed (Asia Pacific) Model version 50N
Countries:
       United States
       Japan
       Australia
       New Zealand
       Indonesia
       Malaysia
       Philippines
       Singapore
       Thailand
       China
       India
       Taiwan
       Korea
       Hong Kong
       ROECD
       non Oil Developing countries
       Eastern Europe and Russia
       OPEC
Sectors:
       Energy
       Mining
       Agriculture
       Durable Manufacturing
       Non-Durable Manufacturing
       Services

Table 2. Health Expenditure, Tourist Arrivals and Sanitation Indicators for Selected
Countries

	Health Expenditure, Total (% of GDP)	Health Expenditure per Capita (Current US$)	Tourist Arrivals (million)	Tourist Arrivals/ Population (%)	Improved sanitation facilities (% of population)
China	5.3	45	33.2	3	29
Hong Kong	4.4	950	13.7	203	100
India	4.9	23	2.5	0	16
Indonesia	2.7	19	5.2	2	47
North Korea	2.1	18	n.a.	n.a.	99
South Korea	6.0	584	5.1	14	63
Malaysia	2.5	101	12.8	53	n.a.
Philippines	3.4	33	1.8	4	74
Singapore	3.5	814	6.7	163	100
Thailand	3.7	71	10.1	16	79
Vietnam	5.2	21	1.4	2	29
US	13.0	4499	n.a.	n.a.	100
Japan	n.a.	n.a.	4.8	4	n.a.
High income OECD	10.2	2771	377.6	n.a.	n.a.
World	9.3	482	696.5	n.a.	55

Source: Table 1 in Lee and McKibbin (2004).

	Temporary Shock				Persistent Shock over 10 years			
	Total Effects	Demand Shift	Cost Rise	Country Risk	Total Effects	Demand Shift	Cost Rise	Country Risk
United States	-0.07	-0.01	-0.06	0.00	-0.07	-0.01	-0.06	0.00
Japan	-0.07	-0.01	-0.06	0.00	-0.06	-0.01	-0.06	0.01
Australia	-0.07	0.00	-0.06	0.00	-0.06	0.00	-0.06	0.01
New Zealand	-0.08	0.01	-0.08	0.00	-0.08	0.00	-0.08	0.00
Indonesia	-0.08	0.01	-0.09	0.00	-0.07	0.01	-0.08	0.00
Malaysia	-0.15	0.01	-0.16	0.00	-0.17	0.01	-0.15	-0.02
Philippines	-0.10	0.04	-0.14	0.00	-0.11	0.03	-0.13	-0.02
Singapore	-0.47	-0.02	-0.45	0.00	-0.51	-0.01	-0.44	-0.05
Thailand	-0.15	0.00	-0.15	0.00	-0.15	0.00	-0.15	0.00
China	-1.05	-0.37	-0.34	-0.33	-2.34	-0.53	-0.33	-1.48
India	-0.04	0.00	-0.04	0.00	-0.04	0.00	-0.04	0.00
Taiwan	-0.49	-0.07	-0.41	-0.01	-0.53	-0.07	-0.39	-0.07
Korea	-0.10	-0.02	-0.08	0.00	-0.08	-0.01	-0.08	0.00
Hong Kong	-2.63	-0.06	-2.37	-0.20	-3.21	-0.12	-2.37	-0.71
ROECD	-0.05	0.00	-0.05	0.00	-0.05	0.00	-0.05	0.00
non Oil Developing countries	-0.05	-0.01	-0.04	0.00	-0.05	0.00	-0.04	0.00
Eastern Europe and Russia	-0.06	-0.01	-0.05	0.00	-0.05	-0.01	-0.05	0.00
OPEC	-0.07	-0.01	-0.05	0.00	-0.09	-0.01	-0.06	-0.02

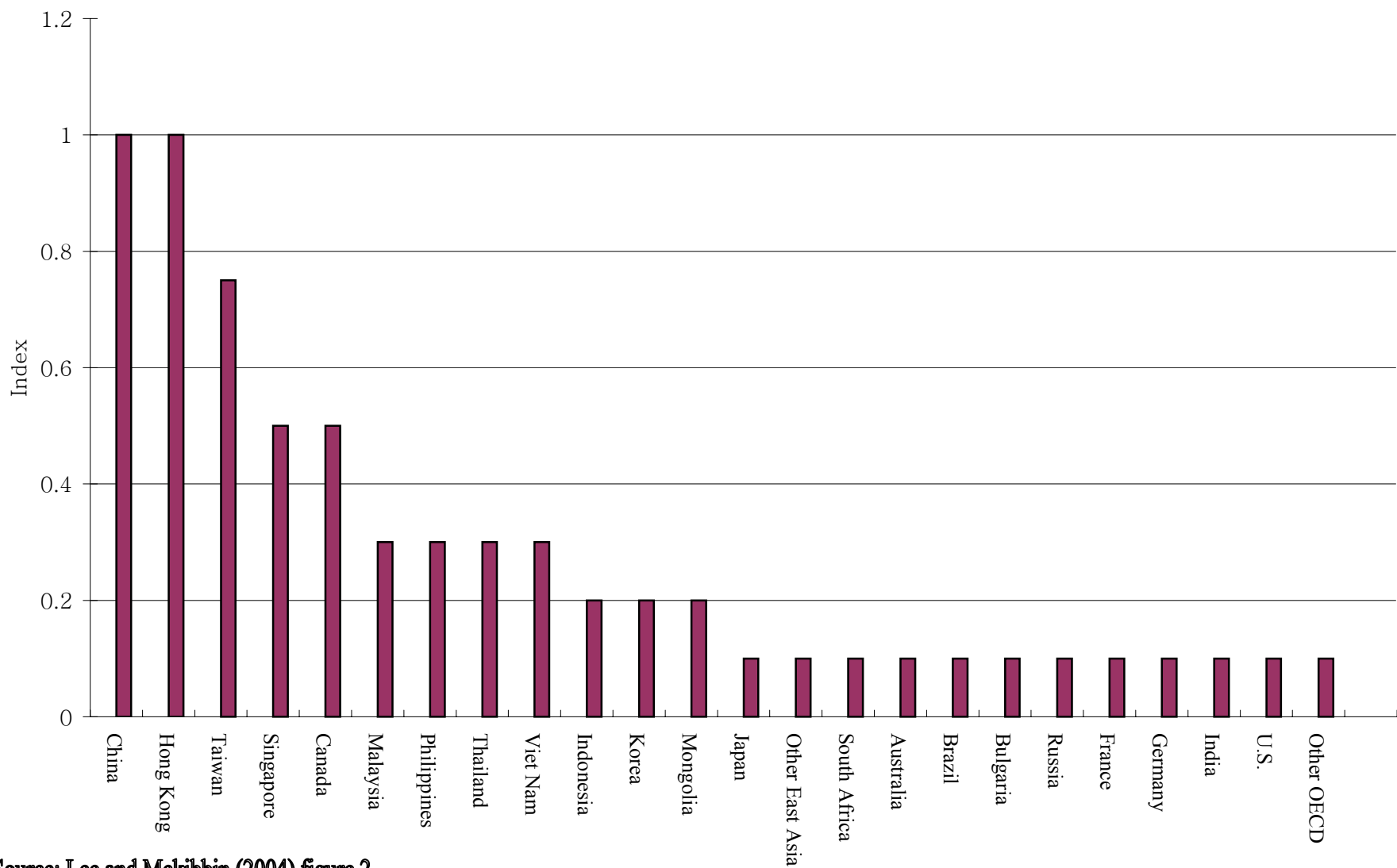**Table 3: Percentage Change in GDP in 2003 Due to SARS**

Source: Table 4 in Lee and McKibbin (2004)

Figure 1. Sectoral Exposure to SARS:
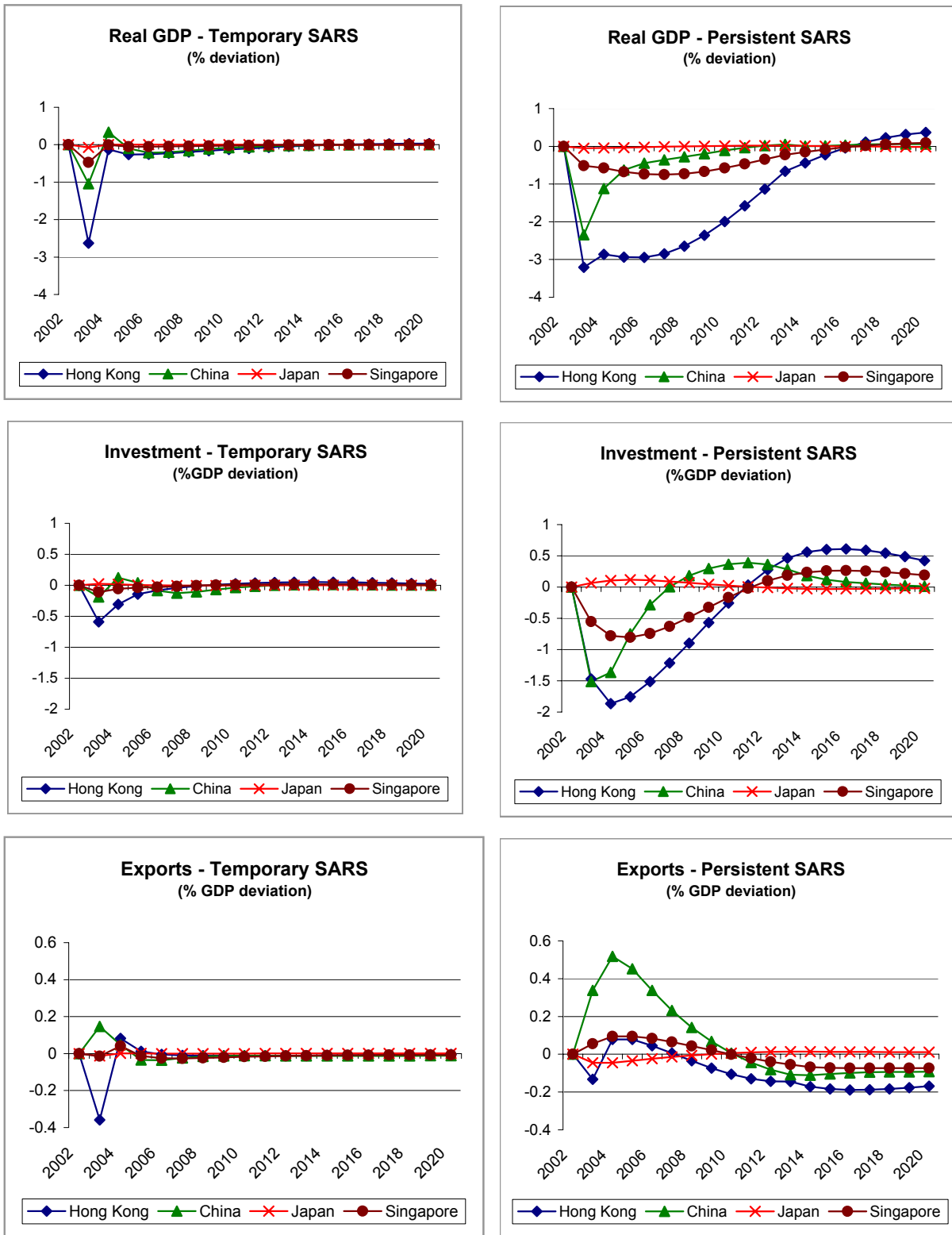## Share of Retail Sales and Travel Industry in Service Sector
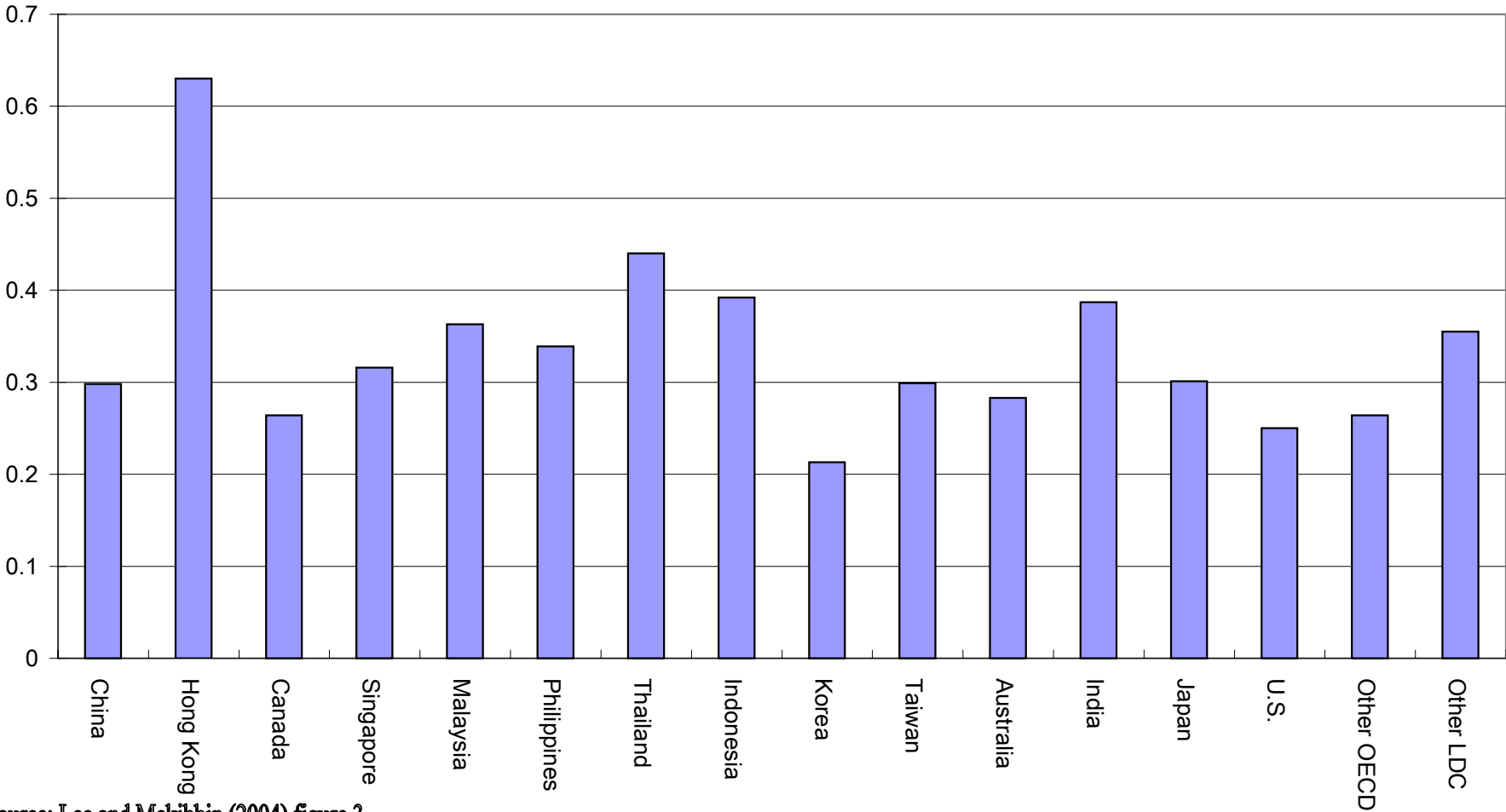
Source: Lee and Mckibbin (2004) figure 3

Figure 2. Global Exposure to SARS
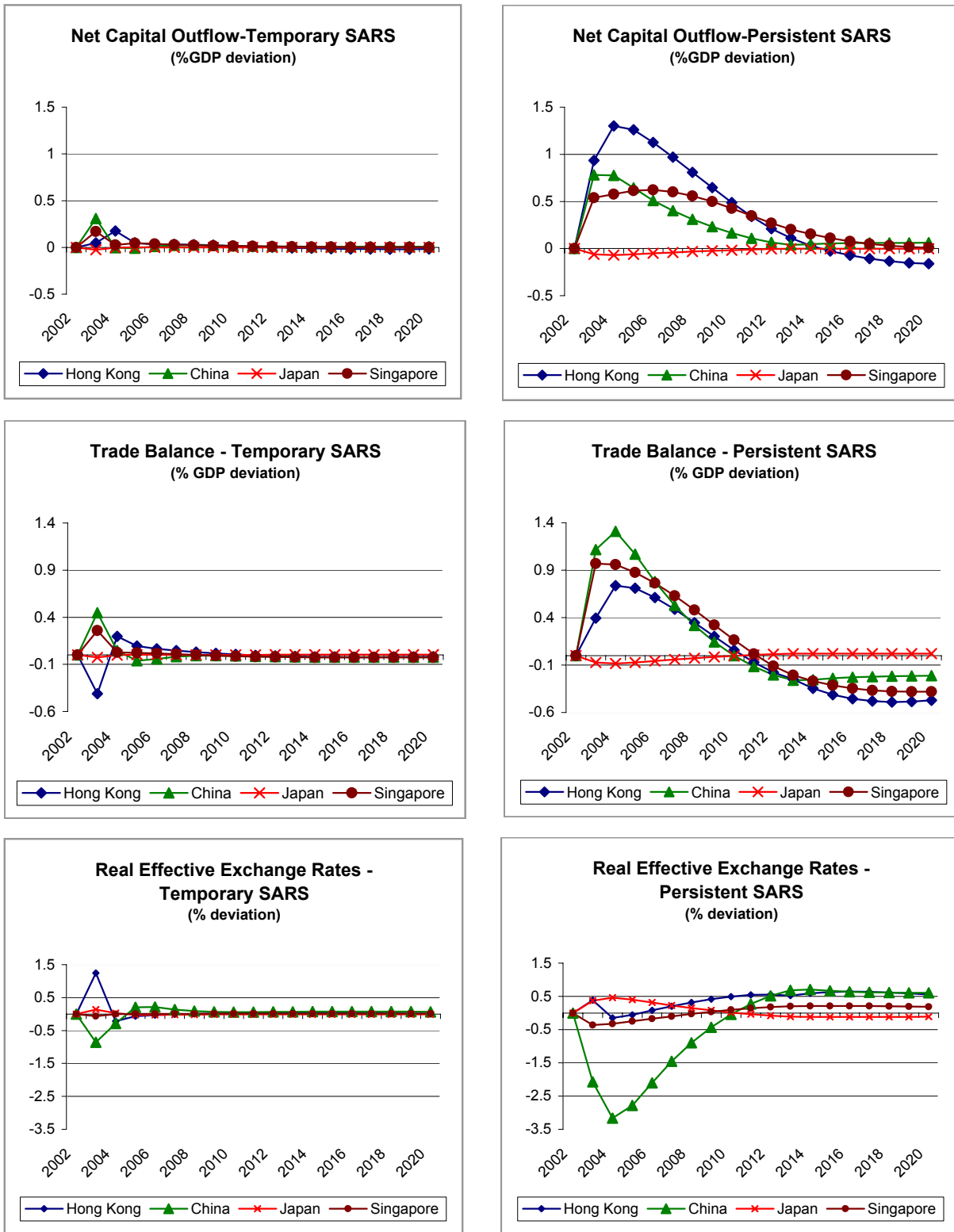

Source: Lee and Mckibbin (2004) figure 2

Figure 3 : Real Impacts of Temporary versus Persistent SARS shock

Real GDP - Temporary SARS
(% deviation)
Hong Kong | China | Japan | Singapore

Real GDP - Persistent SARS
(% deviation)
Hong Kong | China | Japan | Singapore

Investment - Temporary SARS
(%GDP deviation)
Hong Kong | China | Japan | Singapore

Investment - Persistent SARS
(%GDP deviation)
Hong Kong | China | Japan | Singapore

Exports - Temporary SARS
(% GDP deviation)
Hong Kong | China | Japan | Singapore

Exports - Persistent SARS
(% GDP deviation)
Hong Kong | China | Japan | Singapore

Source:Figure 5 in Lee and McKibbin (2004)

Figure 4: Trade and Captial Flow Impacts of Temporary versus Persistent SARS shock

Net Capital Outflow-Temporary SARS
(%GDP deviation)

Net Capital Outflow-Persistent SARS
(%GDP deviation)

Trade Balance - Temporary SARS
(% GDP deviation)

Trade Balance - Persistent SARS
(% GDP deviation)

Real Effective Exchange Rates - Temporary SARS
(% deviation)

Real Effective Exchange Rates - Persistent SARS
(% deviation)

Source: Figure 6 in Lee and McKibbin (2004)

Figure 5: Financial and Sectoral Impacts of a Persistent SARS Shock
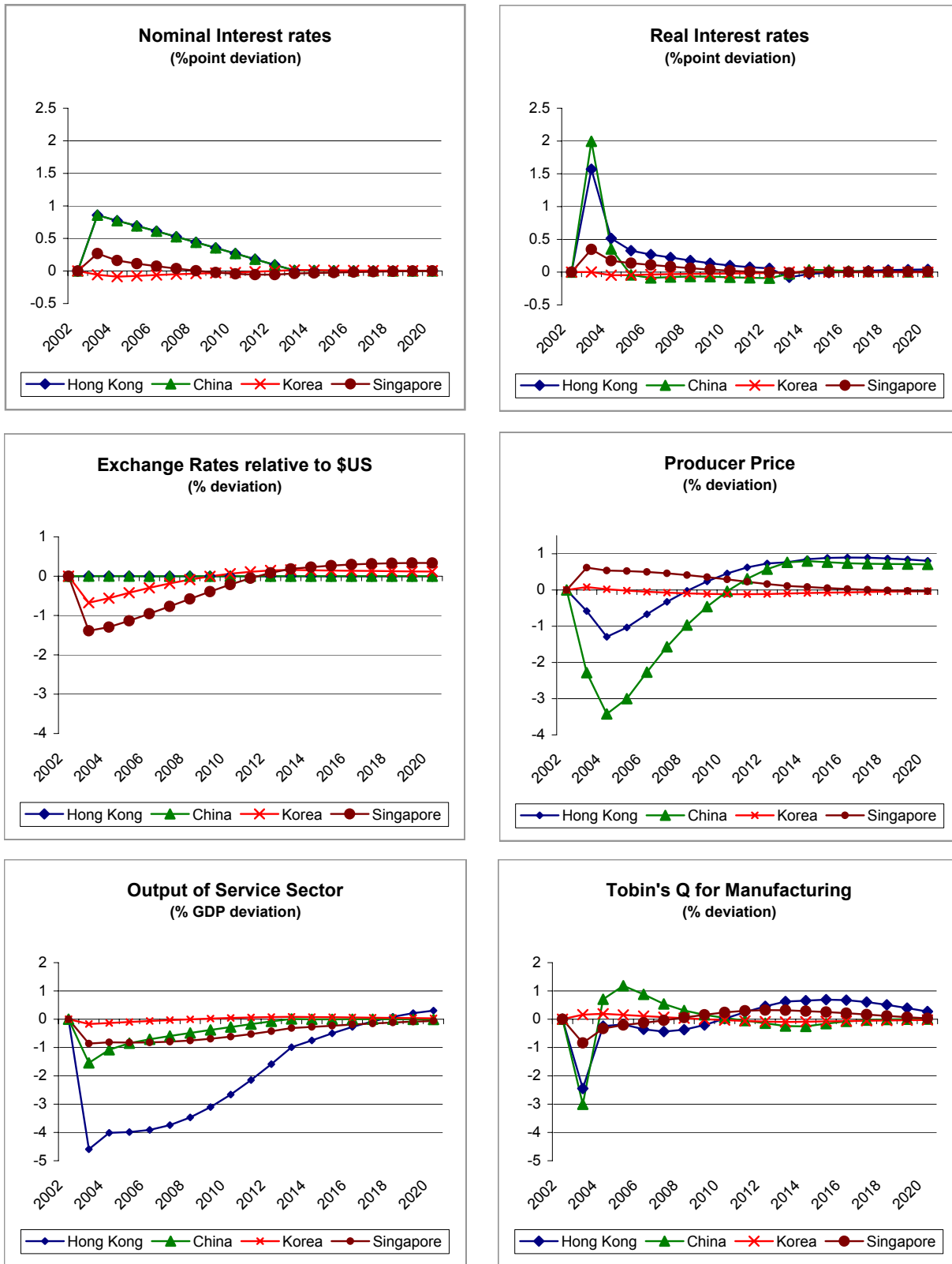
Source: Figure 7 in Lee and McKibbin (2004)

Figure 6: Expected GNP Loss in 2004 in Country X for a Stylized Pandemic (54 scenarios)