Thesis Proposal Review

Understanding Black Swan Infectious Disease Outbreaks

An econometric investigation into the 2002/03 SARS outbreak

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Contents

1 Introduction

The medium and long-term economic consequences of an infectious disease outbreak are sizeable, albeit unclear when compared to the immediate, short-term outbreak repercussions (Bloom and Canning, 2006). Accordingly, there has been little research into the medium and long-term impacts of an epidemic on the macroeconomy.

This PhD thesis is therefore intended to comprise a series of papers that contribute to a greater understanding of the macroeconomic consequences of a "Black Swan" infectious disease outbreak. With black swan disease outbreaks being those that are both unexpected and unanticipated, characterised by large financial or magnitude costs, this research will focus on the 2002/03 Severe Acute Respiratory Syndrome (SARS) outbreak as a historical case study.

1.1 Background

In November 2002, the first case of SARS was detected in Guangdong, China. Originally diagnosed as atypical pneumonia, SARS coronavirus (SARS-CoV) was properly identified in early 2003. Over the course of the epidemic, SARS affected individuals living in 26 countries. This resulted in more than 8,000 infected cases (World Health Organization, 2017). By the 5th July 2003, the World Health Organization announced that the SARS outbreak had been contained worldwide (World Health Organization, 2003).

However, in comparison to the actual severity of the outbreak, there was a significant overreaction by individual agents in response to the perceived risk (Fan, 2003; McKercher and Chon, 2004). Most epidemics are unexpected and unanticipated. Yet, the SARS outbreak incurred substantial costs in terms of individual fear regarding the risk of infection and death. This brings to the fore the implications of globalisation on disease spread dynamics and how individuals alter their contact behaviour in response to this.

Previous studies have focused on the financial impact (or, "cost of illness") of the SARS outbreak as a means of understanding the macroeconomic impact of the SARS outbreak. However, this thesis will argue that traditional microeconomic analysis does not take into account the crucial link between infectious disease, contact behaviour, public health policies, and the economy (Brahmbhatt and Dutta, 2008; Keogh-Brown and Smith, 2008). In response to this, this research aims to understand the *magnitude impacts* that were experienced by economies affected with respect to key macroeconomic variables.

Numerous studies have called to the fore the need to establish integrated epidemiological and economic models (Smith, 2006; Smith et al, 2006; Brahmbhatt and Dutta, 2008), accounting for the entire spectrum of dynamics occurring throughout an infectious disease outbreak. This involves tying together four crucial elements:

1. **Biology:** with respect to the type of disease, how it spreads, how fast it spreads, and how it can be treated.
2. **Contact behaviour:** with respect to how individuals alter their contact behaviour in response to the threat of disease transmission.
3. **Policy response:** with respect to governments and policy makers manage and mitigate risk communication and disease prevention efforts.
4. **Economic response:** with respect to how the macroeconomy is influenced by elements 1-3.

Across these four elements, the most essential components to understanding the true effects of an outbreak lie within the impacts of contact behaviour, policy action and risk communication (Keogh-Brown and Smith, 2008; Perrings et al, 2014; McKercher and Chon, 2004). These elements will be further discussed throughout this proposed thesis.

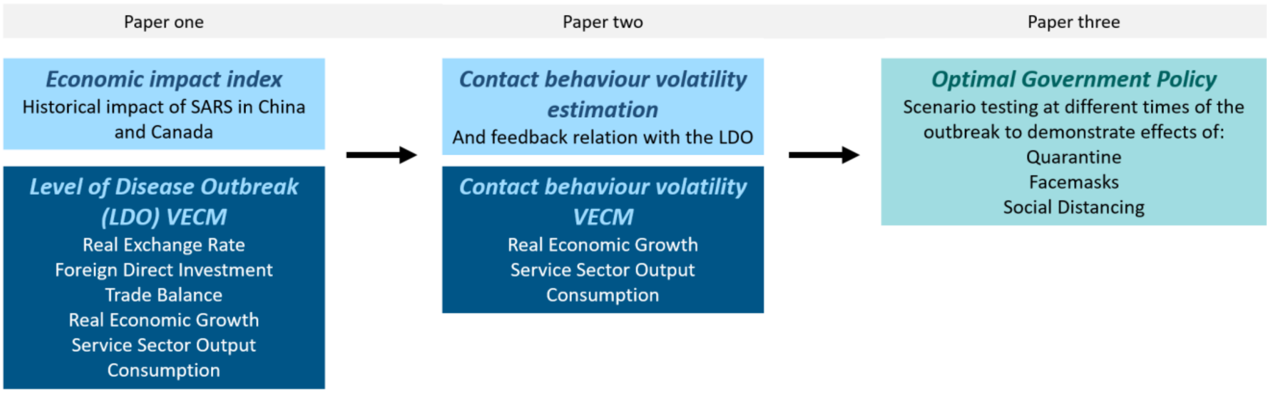
1.2 Research questions

This research will build on the existing base of literature evaluating integrated epidemiological and economic models by addressing the following research questions:

1. What kind of medium-term macroeconomic impacts are experienced during a black swan infectious disease outbreak?
2. What proportion of these macroeconomic impacts can be attributed to fear, or contact behaviour volatility, by individual agents?
3. Given these findings, what is the optimal government policy and risk communication strategy in response to a black swan infectious disease outbreak?

Each research question will comprise a single thesis chapter each. Figure 1.1 below provides a summary of the contents of each paper. Paper one would derive an index of the severity of the SARS outbreak on the economies of China and Canada. This index would then be used as an innovation in a Vector Error Correction Model (VECM) to understand the macroeconomic impacts of the outbreak. Paper two would involve estimating volatility in contact behaviour, and the associated macroeconomic impacts of contact behaviour volatility as an innovation on a smaller VECM. Paper three would then test different scenarios of isolation, facemasks and social distancing on the contact behaviour volatility and level of disease outbreak (LDO) VECM.

Figure 1.1: Research summary



1.3 Motivation and significance

There has been little research conducted that investigates the macroeconomic outcomes of an outbreak, and the role that contact behaviour plays in this. Additionally, the role of government communication and response strategies need to be further evaluated with respect to their impact on disease spread dynamics and contact behaviour. This research will bring together the strengths of economics (that being, an ability to cost and understand the true impacts of events), psychology (in assuming that individuals do not always behave rationally) and policy (in the different ways governments can respond to outbreaks).

2 Estimating the severity and macroeconomic flow-on effects of the 2002/03 SARS outbreak

2.1 Context

The first paper of this thesis will apply time-series econometrics to the 2002/03 SARS outbreak to better understand the medium-term economic consequences of a black swan infectious disease outbreak.

However, in order to understand these macroeconomic impacts, it is necessary to derive a parameter that reflects the power of the level of disease outbreak (LDO), encapsulating the number of people infected and dead, on key macroeconomic variables. Once this is known, it is possible to estimate the magnitude impacts of the LDO on key macroeconomic variables using Vector Error Correction Model (VECM) modelling.

This paper will therefore answer the question of:

1. *What kind of medium-term macroeconomic impacts are experienced during a black swan infectious disease outbreak?*

This research question is intended to be answered by arguing that time-series econometrics can effectively capture the dynamics of the macro economy in response to the LDO.

2.2 Current perspectives

There is an abundance of evidence supporting the macroeconomic impacts of the SARS outbreak. Perhaps most importantly, the SARS outbreak was reported to negatively affect economic growth as measured by GDP (Beutels et al, 2009; Fan, 2003; Lee and McKibbin, 2003; Heymann, 2004). Beyond economic growth, countries affected by SARS have also been reported to experience declines in: foreign investment (Keogh-Brown and Smith, 2008; Bloom and Canning, 2006; Fan, 2003; Hanna and Huang, 2004), consumption (Beutels et al, 2009; Fan, 2003; Siu and Wong, 2004), consumer confidence (Fan, 2003), service sector output (including tourism) (Fan, 2003; Bloom and Canning, 2006; Heymann, 2004) and trade (Siu and Wong, 2004; Hanna and Huang, 2004; Heymann, 2004).

The ordering of variables is based on Fan (2003), which details that the real exchange rate (E) of the country affected is the most sensitive to the news of an outbreak. Following this, the economy is likely to then see a reduction in Foreign Direct Investment (FDI) and the trade balance (TB). The collective action of these influences is anticipated to result in a decline in real economic growth (G). Meanwhile, domestically, consumption (C) and service sector output (SO) are likely to decline, as individuals are less likely to want to purchase goods and services where they could be in contact with other (potentially infected) individuals. The conglomeration of all these impacts is likely to negatively affect the real economic growth rate (G) of that country through feedback mechanisms.

Therefore, it is reasonable to assume that an econometric investigation of the macroeconomic impacts of the outbreak would yield significant and/or interesting results. A whole-of-economy approach would also address the implications of a disease outbreak on a closely interconnected and interdependent world (Heymann, 2004).

2.3 Proposed methodology

To measure the macroeconomic impacts of the SARS outbreak on the economies of **China and Canada**, a two-step process will be followed:

1. Estimation of an economic impact index (EII) to determine the level of disease outbreak (LDO) at different points in time
2. Estimation of macroeconomic flow-on effects in the form of a Vector Error Correction Model (VECM)

These country have been selected to provide an examination of the Asian response to the SARS outbreak, in comparison to the Western response. Countries are only incorporated into the analysis once it they reach a threshold number of infected cases (in this case, a minimum number of 10 infected individuals). The date of inclusion, cumulative number of cases and cumulative number of deaths for each country is listed below in Table 2.1.

Table 2.1: Countries included in this analysis

	Cumulative number of cases	Cumulative number of deaths	Date of inclusion (>10 cases)
China	5,327	349	26 March 2003
Canada	251	43	24 March 2003

Source: World Health Organization (2004)

From this table it is clear that China experienced a significantly worse outbreak than Canada. However, available evidence suggests that the behavioural implications and spread of fear in the Western countries (particularly Canada) was extremely disproportionate to actual events (Conly and Johnston, 2003). Naturally, this will be discussed in greater detail in chapter three of this proposal.

2.3.1 Estimating the severity of the SARS outbreak

To conduct an econometric analysis of the impact of the SARS outbreak on the affected economies, an economic impact index (EII) illustrating the impact of the LDO is required, essentially to act as an innovation (or “shock”) to the macroeconomy.

Data

For data pertaining to the LDO, daily data reported by the World Health Organization (2004) details the number of unique individuals that are infected, dead or recovering for each day of the outbreak. In addition, macroeconomic data for the following variables would be collated:

- real exchange rate,
- Foreign Direct investment (FDI),
- trade balance,
- consumption,
- service sector output, and
- real economic growth.

Data has been sourced from central statistical agencies, central banks and government websites for the date range March 2003 through to March 2007. Effective exchange rate indices (real exchange rate) were obtained from the Bank for International Settlements for all countries. Additionally, data for China was solely sourced from the National Bureau of Statistics China for all the above indicators, and likewise data for Canada was sourced from Statistics Canada, Canada’s national statistical agency.

Given that the SARS outbreak occurred over a relatively short time period (approximately five months of disease spread followed by a unknown period of macroeconomic repercussions), it is proposed that daily LDO data be aggregated into monthly form, accompanied by monthly macroeconomic data for the above indicators. The time period of analysis is March 2003 to March 2007 (n=49).

Economic impact index

The economic impact index is based on the highest correlation between the LDO (number of unique individuals infected or dead for each time period) and macroeconomic outcomes (changes to the dollar value of selected macroeconomic variables). This index is based on, and adapted from, Yaya (2009).

Macroeconomic variables used to inform the index are to be split into two categories, namely: **global** (trade balance and foreign direct investment) and **local** (real economic growth, service sector output and consumption). Across the entire period of analysis (March 2003 to March 2007), the correlation between total, global and local indicators and the LDO will be calculated using Excel.

To calculate the EII, the simple correlation coefficient of the number of people infected and dead against total macroeconomic outcomes (β_I and β_D) is multiplied by the number of unique individuals infected or dead at time t to provide an index value.

$$Economic\ impact\ index = \log[\alpha_0 + \beta_I \cdot I + \beta_D \cdot D + \varepsilon] \quad (1)$$

Using this index, the LDO in each month can be determined by taking the logarithm of the sum of one and the value of the impact index (Yaya, 2009). This value is between zero and one.

$$LDO = \log(1 + EII) \quad (2)$$

This indicator can then be used as an innovation designed to shock the economy with the changing disease dynamics experienced throughout the outbreak. Consequently, the macroeconomic outcomes of the SARS outbreak may be evaluated econometrically.

Macroeconomic flow-on effects: VECM model

Estimation of the LDO using the EII allows for calculation of the macroeconomic impacts of the SARS outbreak using VECM analysis. This VECM analysis, and its associated impulse response functions (IRFs), can be used to understand the magnitude impact of the SARS outbreak on the three countries under investigation.

The data collated has been found to be non-stationary and cointegrated. Following identification of all data being non-stationary (using the Augmented Dickey Fuller test), it is necessary to test for cointegration between the variables. The Johansen System Cointegration Test has been used to determine the number of cointegrated vectors, using a trace test. The trace statistic assesses the null hypothesis of r cointegrating relations against the alternative of n cointegrating relations, where n is the number of variables in the system for r=0,1,2…n-1.

Given that all or some of the variables are cointegrated, it can be assumed that a long-term equilibrium relationship exists between the variables. In this case, the VECM can be applied to evaluate the short run properties of the cointegrated series in levels. As per Enders (2010), a n-variable model has an error-correction representation if it can be formally represented as a (n·1) vector of I(1) variables $x_t = (x_{1t}, x_{2t}, \ldots, x_{nt})'$ in the following form:

$$\Delta x_t = \pi_0 + \pi x_{t-1} + \pi_1 \Delta x_{t-1} + \pi_2 \Delta x_{t-2} + \cdots + x_p \Delta x_{t-p} + \varepsilon_t \quad (3)$$

where π_0= an (n·1) vector of intercept terms with elements π_{i0}

π_i = (n·n) coefficient matrices with elements $\pi_{jk}(i)$

π = a matrix with elements π_{jk} such that one or more of the $\pi_{jk} \neq 0$

ε_t = an (n·1) white noise error vector with elements ε_{it}, noting that disturbance terms may be correlated.

If there is an error-correction representation of these variables (x_t), there is a linear combination of the variables that is stationary. Solving equation (3) for πx_{t-1} thus yields:

$$\pi x_{t-1} = \Delta x_t - \pi_0 - \sum \pi_i \Delta x_{t-i} - \varepsilon_t \quad (4)$$

Given that the expressions on the RHS of the equation are stationary, πx_{t-1} must therefore also be stationary.

This kind of level analysis will be indicative of the nature of the relationships between the variables, in the absence of specific parameter estimates, as supported by Sims (1980) and Sims, Stock and Watson (1990). In this way, the rich dynamic relationships among variables may be analysed in a manner that allows insight into the response of variables following a policy change or shock.

A separate VECM would be run for each country and would include each of the global and local variables.

Adjusting for external flow-on effects

Changes in the macroeconomic variables are likely not to be exclusively determined by the error correction term but might instead be determined by unknown and/or immeasurable external factors.

A summary of changes that may have affected the results is included below.

China – De facto trade agreement with India (2003), trade agreement with 10 SE Asian countries (2004), deteriorating relations with Japan, explosion of a chemical plant poisons the Songhua region (2005), new railway line (2006), significant drought (2006) and the China-Africa summit in 2006.

Canada – political tensions, government money scandal (2004), and the approval of same sex marriage (2005).

Results of the VECM models will be summarised using IRFs which will be used to illustrate the indicative magnitude impacts of the LDO innovation on each macro economy. If interesting, the forecast-error variance decomposition would also be discussed. Preliminary results are provided in the following section.

2.3.2 Preliminary results

In order to run the VECM analysis, an Economic Impact Index (EII) was generated, which could then be converted into a parameter detailing the overall Level of Disease Outbreak (LDO) in each economy at any given point in time.

The global LDO indicator is reflective of the power of the number of people infected and dead from SARS on global macroeconomic indicators (trade balance and foreign direct investment). Concordantly, the local LDO indicator reflects the power of the SARS outbreak on the local macroeconomic indicators (real economic growth, service sector output and consumption). Total LDO considers the impact of the SARS outbreak on both local and global indicators combined.

First, to calculate the LDO, the EII multiplies the correlation coefficient of the number of people infected and dead by the correlation coefficient for the impact of the outbreak on all economic indicators (total), as per equation (1). Future analysis will look to separate out the global and local effects from the total.

Table 2.2 details the correlation coefficients used to calculate the EII at the total, global and local levels for the entire duration of the outbreak (March 2003 through to July 2003).

Table 2.2: Level of disease outbreak

	Correlation China		Correlation Canada	
	Infected	*Dead*	*Infected*	*Dead*
Global	0.91	0.85	-0.64	-0.56
Local	0.95	0.95	0.76	0.78
Total	**0.91**	**0.85**	**0.66**	**0.69**

From these results, it is clear that the SARS outbreak is correlated with both local and global economic outcomes across all countries, with the exception of Canada's global indicators. This may be reflective of the global perception of the SARS outbreak to be diminished in comparison to the domestic overreaction to the disease. China was found to be most correlated with negative economic outcomes, with 91% and 85% of the number of people infected and dead respectively in a given month explaining total economic consequences.

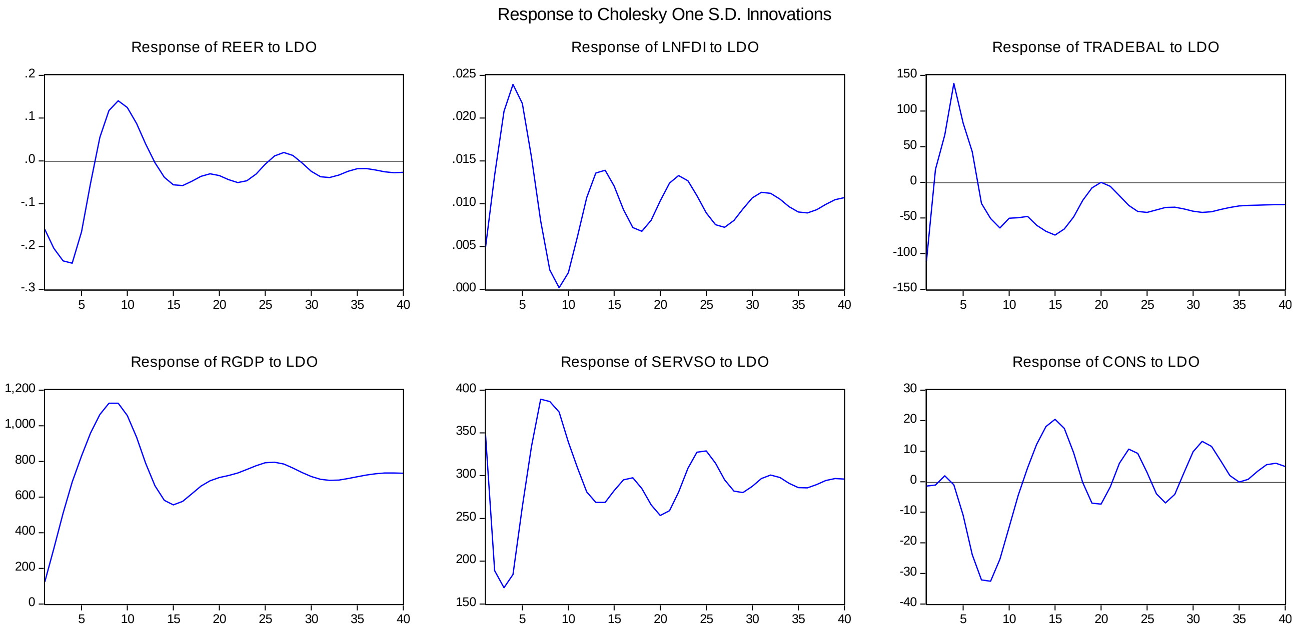
For the analysis conducted below, the total LDO index derived from the EII has been used to shock the economy.

Impulse Response Functions (IRFs) illustrate the responsiveness of the dependent variables in the VECM to a given shock. In this case, a unit shock is applied to the error term of the LDO, which in turn affects the VEC system over time. This thesis will use a standard Choleski decomposition to identify the short run effects of shocks on the levels of the endogenous variables in the VECM.

The Johansen System Cointegration Test found three cointegrating equations for each country under analysis. This cointegration rank was incorporated into the result estimation, performed using Eviews 8. No additional restrictions were placed on the data thus far.

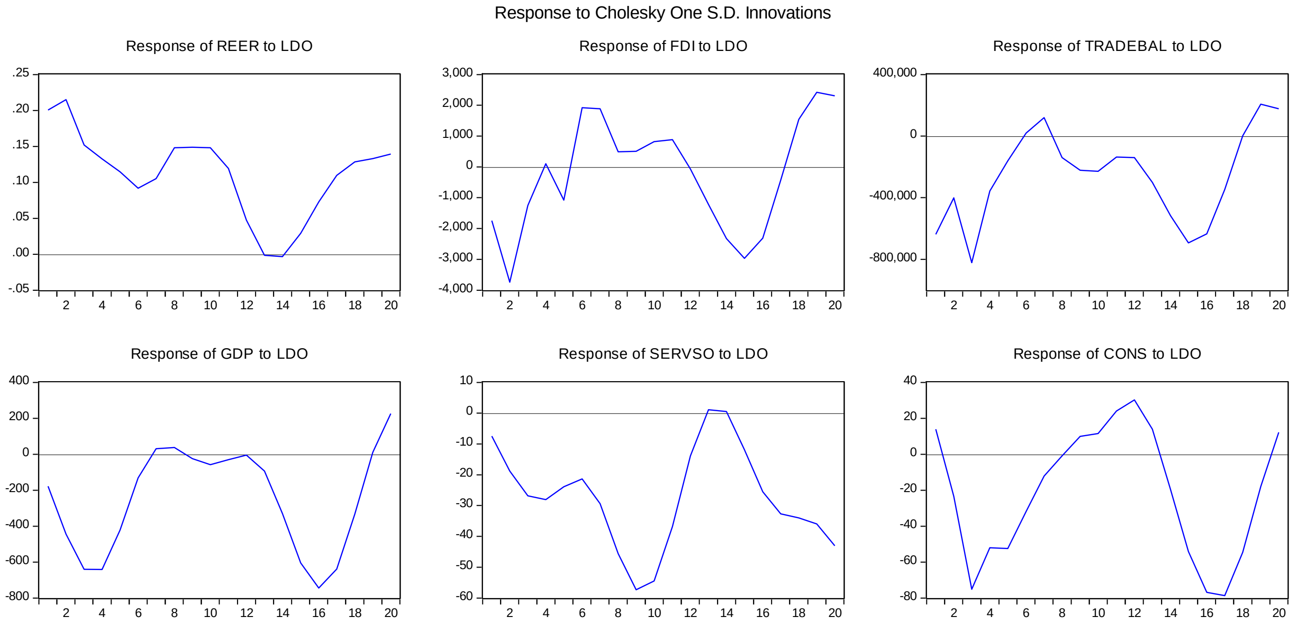
Figures 2.1 to 2.2 present IRFs for a 1 standard deviation innovation in the LDO. On the x axis, time is measured in months. Alternatively, the y axis reflects the direction and intensity of the impulse in the dependent variable away from its original level.

Figure 2.1: Preliminary VECM results Canada



The result for Canada indicates LDO innovations have an immediate and significant negative impact on the real exchange rate, service sector output and consumption. Foreign direct investment, real economic growth and the trade balance are also negatively affected, however with a lag. After approximately 15 months, all variables appear to return to a stable level.

Figure 2.2: Preliminary VECM results China



The result for China indicates that all variables under analysis experience an initial decrease in response to the LDO innovation. Foreign Direct Investment, economic growth, the trade balance and consumption all appear to decrease, then return to original (or in some instances, higher than original) levels. Conversely, the real exchange rate decreases before returning to a lower than original level. Service sector output was found to decrease significantly, in a pattern similar to a cubic curve.

Summarising the results

The results from Figure 2.1 and 2.2 have been summarised in Table 2.3.

Table 2.3: Summary of VECM results to a 1 standard deviation innovation in LDO

Country	Variable	Time period of immediate increase/decrease
Immediate increase followed by decrease to stabilisation/volatility		
Canada	RGDP	7 months
	FDI	4 months
	TradeBalance	4 months
China	TradeBalance	2.5 months
Immediate decrease followed by increase to stabilisation/volatility		
Canada	REER	4.5 months
	Service Sector Output	2.5 months
	Consumption	8 months
China	FDI	2.5 months
	Consumption	2.5 months
	Service Sector Output	8.5 months
	GDP	4.5 months
	REER	6.5 months
Persistent decrease		
China	REER	6.5 months

3 Understanding fear mechanisms during the 2002/03 SARS outbreak

3.1 Context

The previous paper proposed to estimate the macroeconomic effects of a black swan infectious disease outbreak using historical data from the 2002/03 SARS outbreak in China and Canada. This paper seeks to extend this traditional economic analysis by incorporating "fear", or, contact behaviour volatility, to measure impacts in response to a black swan outbreak. Magnitude impacts of this enhanced model will likewise be estimated using VECM modelling.

This paper will therefore answer the question of:

2. *What proportion of these macroeconomic impacts can be attributed to fear, or contact behaviour volatility, by individual agents?*

This research question is intended to be answered by arguing that time-series econometrics can essentially capture the dynamics of the economy in response to the outbreak, *including* the effects of an overreaction by individual agents' contact behaviour.

3.2 Current perspectives

The 2002/03 SARS outbreak sparked significant debate around the role of fear and expectations by individual agents during a large and unexpected outbreak.

In an increasingly connected world, expectations now play a larger role than ever. This implies that the effects of a disease outbreak have the potential to spiral significantly out of proportion to the number of infected people. In the case of the SARS outbreak, this was primarily attributable to the heightened sense of alarm and uncertainty provoked by a fast-spreading, unknown disease (Bloom and Canning, 2006; Heymann, 2004). As noted by Fan (2003), this disproportionate psychological impact was likely to be the result of both:

a. the nearly costless and rapid transmission of information across social networks, and
b. the lack of qualified medical information on the disease.

The indirect costs of the SARS outbreak can therefore be viewed as a direct function of the public's perception of the risk of becoming infected, and the perceived consequences of infection (Smith, 2006). Such fast speed of contagion (of both disease spread and fear) therefore accounts for new incentive for people to avoid social interactions across the globe (Lee & McKibbin, 2003).

However, the level of fear experienced in one country to the next is not uniform. For example, while Canada had significantly fewer cases of SARS than Beijing or Bangkok, the level of fear was just as severe (Bloom and Canning, 2006). Differences between countries can be examined by looking at differences in prevalence elasticities for each population. Introduced by Geoffard and Philipson (1996), prevalence elastic behaviour occurs when individuals alter their behaviour according to the disease, having both economic and epidemiological consequences. This thus drives changes to the rate of new infections and overall disease prevalence (Perrings et al, 2014). Brahmbhatt and Dutta (2008) detail this as being a natural function of self-interested, forward looking individuals adapting their behaviour in response to the threat posed to them.

In other words, private demand for prevention may be prevalence elastic up to a certain point of disease spread (Philipson, 2000). Previously, classical epidemiological models have failed to incorporate changes to contact behaviour during infectious disease outbreaks (Epstein et al, 2007; Fenichel et al, 2011). However more recently, studies of social networks (Fenichel et al, 2011) demonstrate that people weigh the expected utility associated with decisions which may include the costs of future infection against the benefits of different levels of interpersonal contact (Halloran et al, 2008; Geoffard & Philipson, 1996; Kremer, 1996; Philipson, 2000). It is therefore crucial to understand how government policy may influence contact behaviour as a driver of the transmission rate and associated macroeconomic consequences.

3.3 Proposed methodology

This paper does not propose to re-simulate the SARS outbreak with additional behavioural parameters. Rather, it seeks to take known parameters from the SARS outbreak to estimate an aggregate parameter for contact behaviour, which can then be analysed in terms of economic implications.

3.3.1 Estimating contact behaviour

Following Fenichel et al (2011), a traditional Susceptible Infected Recovered (SIR) model of disease transmission is proposed, which includes an additional parameter for contact behaviour. This model has been adapted from the original model proposed in Fenichel et al (2011) to include demographic augmentation[1]. These adapted equations specify that:

$$\frac{dS}{dt} = \mu - \frac{c(\cdot)\beta SI}{N} - \mu S$$

$$\frac{dI}{dt} = \frac{c(\cdot)\beta SI}{N} - \gamma I - \mu I$$

$$\frac{dR}{dt} = \gamma I - \mu R$$

Where: μ is the natural mortality rate and crude birth rate, I= number of infected individuals, S= number of susceptible individuals, R= number of recovered/immune individuals, β= transmission rate, γ= recovery rate and c(·)= the rate that susceptibles contact others, ergo $\frac{c(\cdot)I}{N}$ is the rate that susceptibles contact infectious individuals.

It is therefore possible to derive a time series estimate for contact behaviour, given we know all the parameters above from the SARS outbreak and the literature, other than c(·).

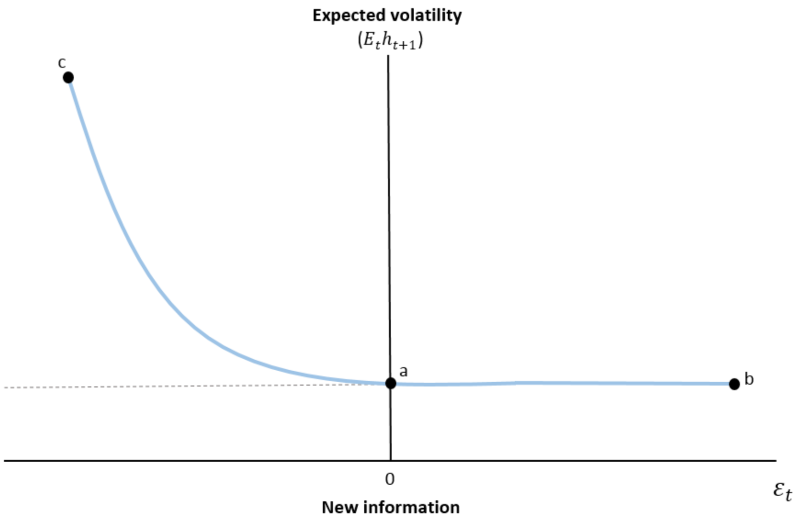
Following estimation of a contact behaviour parameter, it is of interest to determine how volatile this variable was during the outbreak, using Autoregressive Conditional Heteroskedasticity (ARCH) techniques discussed in section 3.3.2.

3.3.2 Estimating contact behaviour volatility

To calculate volatility in contact behaviour, media signals are categorised into “bad news” and “good news” under an Exponential Generalised Autoregressive Conditional Heteroskedastic (EGARCH) framework. Here, bad news is assumed to have a more pronounced effect on contact behaviour than good news. The reasoning for this is that individuals are more likely to assume a worst-case scenario when an unexpected infectious disease breaks out on a global scale. Following Enders (2010), “new information” is measured by the size of the error term ε_t and thus the expected volatility of this new information is measured by $E_t h_{t+1}$. This asymmetric relationship is illustrated in Figure 3.1.

[1] Demographic augmentation based on Keeling and Rohani (2008).

Figure 3.1: Expected volatility and media signals



Source: Adapted from Enders (2010)

When there is a media signal about an outbreak, the level of expected volatility automatically rises from 0→a. When the media signal is positive, i.e. "good news", volatility remains steady along *ab*. Alternatively, when the media signal is negative, (i.e. "bad news" such as increasing number of infected people in that particular country), volatility increases along *ac*. Since segment *ac* is steeper than *ab*, a positive media signal of new information will have a smaller effect on volatility than a negative media signal.

An EGARCH (1,1) model can therefore evaluate the asymmetric effect of news via:

$$\ln(h_t) = \alpha_0 + \alpha_1 \left[\frac{e_{t-1}}{h_{t-1}^{0.5}}\right] + \lambda_1 \left|\frac{e_{t-1}}{h_{t-1}^{0.5}}\right| + \beta_1 \ln(h_{t-1}) \quad (8)$$

Where h_t is the conditional variance of the error (e_t) sequence.

This model does not impose non-negativity constraints on the coefficients, due to the log linear form of the equation. The size and persistence of shocks can therefore be interpreted in a more natural form due to the EGARCH model utilising the standardised value of $\left[\frac{e_{t-1}}{h_{t-1}^{0.5}}\right]$. Theoretically, if this standardised value of the error term is indeed positive, the effect of the shock on the log of the conditional variance can be expressed as $(\alpha_1 + \lambda_1)$. Alternatively, if the standardised value is negative, the effect of the shock on the log of the conditional variance is $(-\alpha_1 + \lambda_1)$.

As per Figure 3.1, contact behaviour only becomes volatile in the case of "bad news". Therefore, a more realistic adaptation of equation (8) would be:

$$\ln(h_t) = \alpha_0 + \alpha_1 \left[\frac{e_{t-1}}{h_{t-1}^{0.5}}\right] + \beta_1 \ln(h_{t-1}) \quad (9)$$

Where the coefficient λ_1 is excluded due to the fact that volatility is assumed to remain at level α_0 following a media signal. In this vein, if the standardised value of $\left[\frac{e_{t-1}}{h_{t-1}^{0.5}}\right]$ is positive, the effect of the shock on the log of the conditional variance can be expressed as α_1. Alternatively, if the standardised value is negative, the effect of the shock on the log of the conditional variance is $-\alpha_1$.

3.3.3 Testing for a feedback relationship between the level of disease outbreak and contact behaviour volatility

In order to make a direct comparison between the economic consequences of the SARS outbreak without fear and the SARS outbreak with fear, it is important to determine the existence of a feedback relationship.

This section would deploy Granger-causality testing to examine the relationship between the level of disease outbreak index (LDO) derived in Chapter 2, and contact behaviour volatility (CB^{vol}). For estimation purposes, a bivariate Granger-causality model of the following form would be specified:

$$\beta_t = \alpha_0 + \sum_{i=1}^{n} \alpha_i \beta_{t-i} + \sum_{i=1}^{n} \gamma_i \, h_{t-i} + \varepsilon_t \qquad (10a)$$
$$h_t = \beta_0 + \sum_{i=1}^{n} \beta_i \, h_{t-i} + \sum_{i=1}^{n} \delta_i \, \beta_{t-i} + \vartheta_t \qquad (10b)$$

Where β_t represents the level of disease outbreak and h_t represents a measure of contact behaviour volatility obtained from the EGARCH model. In equations (10a) and (10b), the lagged terms β_{t-i} and h_{t-i} appear as explanatory variables, indicating the cause and effect relationship between these series. Following Leamer (1985), a limited sense of Granger-causality ('precedence') would be applied to this scenario, given the following condition holds: the sum of the coefficients of contact behaviour volatility must not be statistically zero following the regression of the LDO on lagged LDO and lagged contact behaviour volatility. This implies, in equation (7a), that $\sum \gamma_i$ (i= 1, 2, …) is not statistically zero. On the other hand, the LDO is causing contact behaviour provided that the regression of contact behaviour volatility on lagged contact behaviour volatility and lagged LDO, the sum of the coefficients of LDO (as per equation 7b, $\sum \delta_i$ (i= 1, 2, …)) is not statistically zero. Alternatively, it may be found that there is a two-way causation between the variables. This would be true if both of the above conditions are met.

3.3.4 VECM model specification

A VECM of the same functional form as that defined in section 2.3.1 would be developed, with fewer parameters, and a different innovation (LDO to be replaced with CB^{vol}). Direct comparison can be made with the model defined in section 2.3.1, provided a Granger-causal feedback relationship is found to exist between the LDO and CB^{vol}. Local variables would be included in this VECM, as fear and panic are anticipated to primarily influence domestic variables.

Local variables:

- Consumption
- Service Sector Output
- Real Economic Growth

Here, volatility in contact behaviour (as a reflection of fear) is now driving the macroeconomic impacts of an outbreak. The number of parameters included in the model has been condensed to only evaluate the key variables likely to be directly affected by a change in contact behaviour.

Results of the VECM models will be summarised using IRFs which will be used to illustrate the indicative magnitude impacts of the CB^{vol} innovation on each macro economy. If interesting, the forecast-error variance decomposition would also be discussed.

4 Optimal government policy and risk communication in response to an unexpected infectious disease outbreak

4.1 Context

This paper will seek to understand how various government policy interventions may shape and influence disease transmission, spread and duration. Building on the framework of contact behaviour introduced in chapter three, this paper will answer the question of:

3. *Given these findings, what is the optimal government policy and risk communication strategy in response to a black swan infectious disease outbreak?*

This research question is intended to be answered by arguing that disease spread dynamics can be altered to include the effects of government policy and risk communication, including isolation and social distancing campaigning. In turn, each intervention discussed can have a significant and/or interesting impact on macroeconomic outcomes.

4.2 Current perspectives

In 2000, Philipson (2000) stated that current analysis of outbreaks did not consider the incentives created by the increasing prevalence of a disease, or the desirability of public health measures. Since this paper was published, research focusing on these incentive structures have developed a clear case for incorporating a behavioural understanding of incentives into government policy designed at targeting infectious disease agents (De Valle et al, 2005; Fenichel et al, 2011).

However, debate surrounds the optimal level of information, transparency and credibility required to encourage individuals to engage in disease risk minimising behaviour (Fan, 2003). Keeping in mind the balance between overreaction and underreaction by the general population, the importance of a timely, transparent and credible public information strategy is clear (Brahmbhatt and Dutta, 2008; Keogh-Brown and Smith, 2008; Fan, 2003; Bloom and Canning, 2006).

Beyond the dissemination of information, the optimal modes of control of infectious disease outbreaks are dependent on the nature of the disease, the number of people susceptible to (and infected by) the disease, treatment options, and the discount rate applied (Perrings et al, 2014; Brandeau et al, 2003). During the SARS outbreak, containment strategies included contact management, infection control, temperature screening, mask use, isolation, quarantine and monitoring of travellers (Cetron et al, 2004). When a disease is initially unknown, quarantine and isolation are cited as being highly effective tools in limiting the spread of disease (Cetron et al, 2004; Bloom and Canning, 2006).

However, whether or not quarantine and isolation was effective during the SARS outbreak differed between countries. In Canada, approximately 100 people were quarantined for each confirmed case of SARS. This was both inefficient and ineffective, particularly when compared to Beijing. In Beijing, an average of only 12 people were quarantined for each confirmed SARS case (Schabas, 2004). While the strategy deployed by Beijing was more effective, the Center for Disease Control and Prevention (2003) noted that quarantine efforts would have been greatly enhanced if authorities focused “only on persons who had contact with an actively ill SARS patient”, as echoed by Cetron et al (2004).

These concepts and findings will be further discussed in light of the modelling that will be undertaken in this chapter.

4.3 Proposed methodology

This paper would re-run the VECM model (with LDO and then contact behaviour) developed in Chapter 2 and 3 to see how changes in government policy changes affect the macroeconomy. The methodological foundations of the VECM remain the same as that in Chapter 2.

Referring back to the original disease spread dynamics equations with contact behaviour, the distribution of individuals across the susceptible, infected and recovered disease classes is as follows:

$$\frac{dS}{dt} = \mu - \frac{c(\cdot)\beta SI}{N} - \mu S$$

$$\frac{dI}{dt} = \frac{c(\cdot)\beta SI}{N} - \gamma I - \mu I$$

$$\frac{dR}{dt} = \gamma I - \mu R$$

Throughout this paper, government policy changes will be reflected in the form of changing key parameters – such as, the number of people infected (I), the transmission rate (β) and contact behaviour (c(·)). Three policy interventions will be discussed in light of the SARS outbreak, detailed below.

4.3.1 Isolation

This scenario would look at the economic repercussions of a set portion of the infected population being set aside into isolation. Isolation therefore works to directly reduce the transmission of disease.

A mathematical model of De Valle et al (2005) modelled the spread of smallpox with various classes of social activity; including normal, less active and those in isolation (not active). Isolation was simulated by moving a fixed proportion of the infectious group of individuals into the isolated class each day.

In order to determine the number of infectious individuals entering the isolated class throughout the SARS outbreak, this paper would refer to the hazard of being isolated as discussed in Fraser et al (2004). In this model, $Y(t,\tau)$ represents the number of people at time t who were infected at time τ ago.

The hazard of being isolated is thus represented as:

$$h(\tau) = -\frac{1}{S(\tau)}\frac{dS(\tau)}{d\tau}$$

$$\Leftrightarrow \; S(\tau) = \exp(-\int_0^{\tau} h(u)du)$$

Thus, by removing a select portion of the infected class from the disease spread dynamics, changes to contact behaviour and overall macroeconomic consequences (measured using the VECM) can be observed.

4.3.2 Provision of facemasks

Airborne diseases such as SARS lend themselves to the use of facemasks as a method of reducing the spread of disease. This scenario will look at how the number of people infected and recovered changes (and their associated macroeconomic consequences) under the following assumptions:

1. The degree of protection from wearing a face mask 'normally' is 45% (Lai et al, 2012).
2. 21% of households wear their facemasks often or always (Macintyre et al, 2009), with a maximum upper bound of 76% (Lo et al, 2005).

These assumptions would feed into a changing transmission rate, β.

4.3.3 Social distancing campaigning

Policies aimed at encouraging people to reduce their number of social contacts (thereby reducing contact behaviour) throughout an outbreak can be investigated. This paper would investigate an arbitrary 5%, 10% and 15% reduction in existing contact behaviour among the populations during the SARS outbreak, noting any differences in overall macroeconomic outcomes as a result of these level decreases. The contact behaviour volatility VECM from Chapter 3 would be used to measure impacts on local indicators in this scenario.

4.3.4 Reporting

Changing the transmission rate, contact rate and number of infected individuals in each scenario will therefore generate unique insights into how the LDO and contact behaviour volatility VECM is changing over time in response to government intervention. These findings would then feed into a broader policy discussion based around optimal health policy during a black swan infectious disease outbreak. Impulse Response Functions will be used to illustrate these changes.

5 Dissertation timeline

Table 5.1: Dissertation timeline

Year	Semester	Coursework	Thesis
2017	1	Coursework (1/8)	Develop TPR
	2	Coursework x2 (3/8)	Finish TPR document
2018	1	Coursework (4/8)	Present TPR, start writing first paper
	2	Coursework x2 (6/8)	Writing first paper
2019	1	Coursework (7/8)	Finish first paper
	2	Coursework (8/8)	Start second paper
2020	1	Completed coursework	Writing second paper
	2	Completed coursework	Finish second paper
2021	1	Completed coursework	Start third paper
	2	Completed coursework	Writing third paper
2022	1	Completed coursework	Finish third paper
	2	Completed coursework	Prepare for thesis submission

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