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The economic impact of quarantine: SARS in Toronto as a case study

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Abstract *Objectives*. Over time, quarantine has become a classic public health intervention and has been used repeatedly when newly emerging infectious diseases have threatened to spread throughout a population. Here, we weigh the economic costs and benefits associated with implementing widespread quarantine in Toronto during the SARS outbreaks of 2003.

Methods. We compared the costs of two outbreak scenarios: in Scenario A, SARS is able to transmit itself throughout a population without any significant public health interventions. In Scenario B, quarantine is implemented early on in an attempt to contain the virus. By evaluating these situations, we can investigate whether or not the use of quarantine is justified by being either cost-saving, life saving, or both.

Results. Our results indicate that quarantine is effective in containing newly emerging infectious diseases, and also cost saving when compared to not implementing a widespread containment mechanism.

Conclusions. This paper illustrates that it is not only in our humanitarian interest for public health and healthcare officials to remain aggressive in their response to newly emerging infections, but also in our collective economic interest. Despite somewhat daunting initial costs, quarantine saves both lives and money.

Introduction

Severe acute respiratory syndrome (SARS) arrived in Toronto on March 7, 2003. The source of the illness was unknown and there was no identified cure or effective course of treatment. A series of events, largely driven by errors in diagnoses, bad luck, and unexplained events of 'super spreading,' led to an outbreak of SARS in the Greater Toronto area. Although Canadian officials struggled to contain the mysterious disease, 438 SARS cases were identified in Canada with 224 occurring in Toronto.[1] Of these cases, 44 resulted in death.[2]

SARS appeared to spread rapidly, leaving public health and medical officials in Toronto faced with an urgent need to control the outbreak as quickly as possible. In the absence of a clear and effective

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course of interventional medical treatment, quarantine was used to stop the spread of infection. Despite the antiquity and known effectiveness of quarantine as a means to halt disease, little research has been done to estimate its cost. Such cost-benefit analysis is critical as health authorities evaluate the efficacy of quarantine in the event of another outbreak of highly infectious disease.

In particular, indirect and direct costs of quarantine may be staggering. Here, we weigh the costs and benefits associated with implementing widespread quarantine by comparing minimal intervention—treating and isolating those already infected, yet not implementing widespread quarantine—with the quarantine of infected individuals and all of their close contacts in order to prevent the spread of infection.

History of quarantine

Quarantine is defined as 'the separation and/or restriction of movement of persons who are not ill but are believed to have been exposed to infection to prevent transmission of diseases.'[3] The practice dates back to the mid 14th century when officials in Venice, Italy forced ships to sit anchored for 40 days in order to prevent plague.[4]

Over time, quarantine has become a classic public health intervention and has been used repeatedly when newly emerging infectious diseases have threatened to spread throughout a population. Healthcare officials often turn to quarantine in the early days of an epidemic, when the infectious agent remains unknown, and when vaccines, antibiotics, and anti-viral drugs are either useless or of little known utility. Even if prophylaxis or treatments were effective, they would likely be in short supply[5]. Because of these obstacles, which limit the effectiveness of modern medicine, quarantine is a useful infection containment mechanism in the early days of an outbreak.

Quarantine during SARS

The efficacy of quarantine was proven globally during the SARS outbreaks of 2003. When SARS first emerged in China, it was thought to be little more than a severe strain of influenza. Eventually this diagnosis was changed to that of 'atypical' pneumonia. Even as more patients sought medical care for fever associated with shortness of breath, no definitive diagnosis was made. Then SARS spread across the world to Scarborough Grace hospital in Toronto. There, the staff was relatively unprepared for such a virulent virus, and SARS spread throughout the city. In the coming months, the virus had a severe impact on both the Canadian health system and economy. The outbreaks of this mysterious disease led to public fear and panic since no one understood the cause of SARS or the method or degree of transmission. The only effective mechanism for containment was quarantine.

Methods

We compared two outbreak scenarios: in Scenario A, SARS is able to transmit itself throughout a population without any significant public health interventions. Infected people are isolated and treated as is the standard of care. In Scenario B, quarantine is implemented early on in an attempt to contain the virus, including the quarantine of first-degree contacts of the index case. By comparing these situations, we can investigate whether or not the use of quarantine is justified by being either cost-saving, life saving, or both. All of the costs were calculated in Canadian dollars unless otherwise noted.

The transmission rate of SARS is influenced by various factors, the most important being the rate of contact between infected and susceptible individuals. Using educated estimates and data about the effective transmission rate of SARS, the population density of Toronto, the number of contacts a typical person makes in one day, and the incubation period of SARS, we have modeled the spread of SARS throughout a population. The number of contacts a typical person comes in close contact with on any given day varies across individuals and locations. The number of contacts is a constant number, k, which is a function of population density, ρ, and the number of days a person is infectious, δ:

$$k = f(\rho, \delta) \tag{1}$$

The communicability of SARS has proven to be heterogeneous across individuals and the type of contact that people have with infected persons.[6] The transmission rate in a hospital setting, whether the patient encounters healthcare workers, visitors, or other patients, is much higher than in a community setting with casual contact. Similarly, spouses and family members of infected individuals have a higher incidence of disease versus casual contacts. The rate of transmission is also affected by whether or not a SARS patient is a 'super spreader.' This unexplained phenomenon occurs when one infected individual is responsible for spreading the virus to a large number of people. It is impossible to identify super spreaders until observation and contact tracing is done retrospectively, but these individuals were responsible for the large clusters of outbreaks in Toronto. During the Toronto outbreaks, one super spreader infected as many as 32 people.[7] To account for the variability of transmission in our model, we represented the efficiency of transmission as a variable, α. The number of infections at each stage is expressed as x_i.

Beginning with the index case, the model is as follows:

$$k\alpha = \text{Primary infections } (x_1) \quad (2)$$

$$x_1 k\alpha = \text{Secondary infections } (x_2)$$

$$x_2 k\alpha = \text{Tertiary infections } (x_3)$$

$$\text{Total number of infections} = 1 + \Sigma(x_i) \quad (3)$$

$$\text{Total number of exposures} = k\Sigma(x_i) \quad (4)$$

The model can be run indefinitely to simulate the spread of infection throughout a population. Preliminary evidence suggests that SARS is most infectious among primary contacts of the index case. The virus appears to lose momentum and become less severe as it is transmitted across contacts. For the sake of simplicity, we assume a constant rate of transmission.

Using the above model to estimate the number of exposed and infected individuals, we assessed the economic impact of each scenario by examining the direct and indirect costs associated with each. Because of the relative scarcity of information on SARS, we relied upon data from other researchers, the popular press, and interviews with those involved in the Toronto outbreaks in order to make educated estimates about unknown or uncertain variables.

Cost of unchecked outbreak

Direct costs for Scenario A, in which there is no intervention of widespread quarantine, were calculated by examining the following variables: the estimated number of people who contract the virus when it is able to spread unchecked, the percentage of SARS patients admitted to the hospital, average length of stay (LOS_H) for hospitalization, average length of stay in the intensive care unit (LOS_{ICU}) and the costs of hospitalization and care in the ICU for infected individuals. We also considered the probability (P) that individuals infected with SARS would be hospitalized or put in the ICU. Eq. (5) captures the direct costs of SARS:

$$P(\text{Hospitalization})(LOS_H \times \text{per diem cost}) + P(\text{ICU})(LOS_{ICU} \times \text{per diem cost}) = \text{Direct cost of SARS/person} \quad (5)$$

Indirect costs associated with the SARS epidemic were measured by calculating income lost by workers as a result of being ill and forced to stay home. Lost income represents the opportunity cost of being infected with SARS. Additionally, productivity is most often measured in terms of wages; therefore foregone income can also be translated into lost productivity as a result of the outbreaks. Using estimates of the per capita annual income in Ontario, we calculated the average daily wage (ω) of workers. Additionally, we examined the average days of work missed, based upon the LOS_H. The lost productivity associated with the outbreaks was calculated, in terms of wages. It is important to note that our estimates are conservative as many SARS patients missed additional days of work before hospitalization and even after being discharged. These data were not readily available, so we relied on records of hospitalization.

Another important variable in the indirect cost of the SARS epidemic was the economic effect of mortality. Of the infected population, typically 11%[8] of SARS cases resulted in death. Based upon our model, we ascertained the number of people who died as a result of contracting SARS. Again, we used average earnings of a worker in Ontario to examine the loss of productivity associated with death. We began by calculating the average age of those who died. Using the life expectancy of the average Canadian, we estimated the number of premature deaths and years of potential life lost (YPLL) due to SARS. Using the average annual salary in Ontario, we quantified each year of life lost in terms of productivity. This rough calculation served as an economic measure of mortality and was included in the indirect costs of SARS per person. The indirect costs of SARS are described in Eq. (6):

$$LOS_H \times \omega + P(\text{mortality})(\text{YPLL} \times \text{annual salary}) = \text{Indirect cost of SARS/person} \quad (6)$$

The aggregate economic cost associated with a SARS outbreak without the intervention of quarantine was calculated by adding the direct and indirect costs per person and then multiplying this figure by the total number of people infected.

Cost of quarantine

In order to estimate the impact of implementing quarantine during an outbreak of SARS, we calculated the direct and indirect costs of establishing and operating a system for quarantining and monitoring potentially exposed individuals.

We began our estimate of the direct costs associated with quarantine by calculating the number of people who were exposed to SARS through close contact with an infected individual. In order to estimate the number of contacts made, we turned to criteria established in Taiwan[9] during the 2003 outbreaks to determine who should be quarantined. Close contacts of an individual with SARS were quarantined if they were: (1) healthcare workers who did not wear protective gear while caring for a SARS patient; (2) family members who provided care to SARS patients; (3) people who worked in the same office or within 3 meters (10 feet) of a SARS patient's work area; (4) friends of SARS patients (as deemed by public health authorities); (5) classmates or teachers who attended class for more than 1 h; (6) people who sat in the same or adjacent three rows from a SARS patient on an airplane; (7) passengers and drivers of public transportation who traveled more than 1 h in the same car or cabin as a SARS patients; and (8) people who had contact with a person under quarantine who received care in a medical facility where a cluster of SARS occurred.

The direct costs associated with quarantine were largely administrative costs. During the Toronto outbreaks of 2003, public health authorities were forced to establish administrative infrastructure to carry out contact tracing and enforcement of quarantine in a matter of weeks. Because quarantine had not been used in the past, all of this infrastructure, including a computer database to keep track of contacts, information and surveillance hotlines, and staff to monitor quarantined individuals' health status, were assembled de novo.[10] It is practically impossible to disaggregate the cost of quarantine from the total government expenditure on SARS, therefore, using data from the first quarter (FY 2003-04) report of the Ontario Ministry of Finance,[11] we have made educated estimates of the costs of developing infrastructure to support and enforce quarantine.

The indirect consequence of implementing quarantine during an epidemic can be measured as lost productivity. Many Canadian workers experienced a loss of income if they were barred from working because of a possible exposure to SARS. Despite the fact that most of these individuals were only exposed to the virus and did not actually contract it, many were not compensated for the time they were forced to quarantine themselves. In fact, some employees lost their jobs although their compliance to quarantine aided in the containment of the virus[12]. We calculated the daily wage of workers, ω and multiplied this by δ, the incubation period of SARS, which is equal to the number of days most people were quarantined for. Total costs associated with quarantine were estimated in Eq. (7):

$$\text{Total cost of quarantine} = k\delta\omega + \text{Fixed administrative costs} \quad (7)$$

We compared the total costs associated with Scenarios A and B to determine if implementing quarantine did indeed save lives and money. Our calculations illustrate the costs and benefits associated with earlier versus later implementation of quarantine.

Savings were initially measured by assuming that the index case was quarantined. The cost of quarantining all of the contacts of the index case was calculated. Then, we calculated the cost of infection for the index case and the people who were infected by him or her. It is important to note that although the index case was quarantined, a subset of people was infected since the virus probably was not identified and isolated before the patient became symptomatic. During this time, the patient was contagious and likely had contact with a number of people. However, once the infectious disease has been identified, all of the contacts of the index case should be quarantined. In the event that any of the quarantined individuals contract the virus, they would be isolated from the public and the virus would be contained. After calculating the costs of infection for a given number of people, we then subtract this figure from the aggregate cost of letting the virus spread unchecked to the maximum number of people. We then compare the cost of infection to the cost of quarantine. The following equation represents savings from quarantine:

$$\text{Total cost of SARS/person} \, (\text{aggregate number of infections} - \text{number infected before quarantine}) = \text{Value of averted infections} \quad (8)$$

$$\text{Equation 8} - \text{Equation 7} = \text{Net savings from quarantine} \quad (9)$$

Results

Cost of unchecked outbreak

According to a study by Avendano et al.,[13] the average length of hospital stay for a SARS patient in Toronto was 14 days. The average per diem cost of hospitalization in Canada is $612.[14] During the outbreak in 2003, 92% of people with SARS were hospitalized,[15] and roughly 25%[16] of those patients spent some time in the intensive care unit (ICU). The average cost of one night in the ICU in Canada is approximately three times the cost of typical care,[17] estimated to be $1836. Although we could not find definite information on the average length of stay in the ICU, we assumed that most patients spent 5 of the 14 days in intensive care.[†]

The indirect costs of SARS were measured by calculating lost productivity, or the opportunity cost, of illness. The income per capita in Ontario is approximately $30 702.[18] After dividing this salary over a 5-day work week, we see that $\omega = \$114/\text{day}$. This is useful in calculating the opportunity cost to individuals of staying home ill or being hospitalized as a result of SARS. Using the LOS_H, 14 days, as an indicator for number of days of missed work, we observe an opportunity cost of about $1600 per person.

Included in our analysis of indirect costs associated with SARS is a measure of the cost of mortality. Given that 11% of people infected with SARS died, we calculated the economic cost to society per life year of premature death. The average life expectancy in Canada is 71.[19] Since SARS disproportionately affected the elderly and healthcare workers, we estimate that the average age of death was 56.[20] This represents an average of 15 years of life lost. In order to assign economic value to each year of life, we examined the average wage of a worker in Ontario as a proxy for productivity. This yields an average of $30 702 lost per life year per worker. Therefore, mortality related to SARS results in a loss of productivity valued at approximately $460 530 per life lost. Although these calculations assume that each individual would work until they were 71—which may not be realistic—they also do not adjust upward for the disproportionate economic productivity of the healthcare workers who died as a result of SARS. Their annual wage is likely to be much higher than average, thus rendering this estimate conservative.

[†] This is likely underestimated since those who were admitted to the ICU were the most severely ill and had a higher probability of mortality.

In order to calculate the aggregate costs associate with SARS, we turned to our model to examine the number of people who could potentially contract the virus. Beginning with the index case of the virus, we estimated the number of people exposed to the virus. The population density of Toronto in 2001 was reported as 793 people per square kilometer.[21] Based on the criteria for transmission in the methods section, we assume that the average person comes in close proximity with at least 10 different people each day. Given that the incubation period of SARS, δ, is 10 days, the index case potentially exposes 100 people to the virus. As stated earlier, α, the rate of transmission, is highly varied across individuals and places of contact. Recent research suggests that lies between 8% and 25%.[22]

Using Eqs. (2–4), we illustrate the spread of SARS. The results for an index case are shown in Table 1 with the rate of transmission varied. Calculations were made based upon Eq. (1). The costs associated with each of these scenarios are shown in Table 2.

Cost of quarantine

After calculating the costs associated with an unchecked spread of a newly emerging infectious disease, we estimated the economic impact of intervening during the epidemic with quarantine. From our model, we see that over a 10-day period, the incubation period of SARS, the typical person encounters 100 other people in the close proximity required for transmission of the virus. Depending on the effective rate of transmission, which we have noted is heterogeneous across individuals and places of contact, one person may be directly responsible for infecting as few as eight and up to 25 other people. Because quarantine involves restricting the movements of exposed individuals, it carries substantial financial costs.

According to the first quarter report of Ontario Finances for FY 2003-04, the provincial government spent $10 million on SARS related administrative costs. Additionally, $1 million were spent to protect the jobs of those who were quarantined and another $1 million was used to the establishment of a SARS Assistance Office which dealt with the interests of employees who took time off of work to either quarantine or isolate themselves. Based upon these figures, we estimate the direct cost of the epidemic to be $12 million.

The indirect costs were measured as productivity lost due to exposed individuals being unable to go to work for at least 10 days. Using the average daily wage of workers in Toronto, we were able to

Table 1 Transmission resulting from index case, α varied

Stage of infection	α=0.08		α=0.15		α=0.25	
	Number of contacts (k)	Number infected (x_i)	Number of contacts (k)	Number infected (x_i)	Number of contacts (k)	Number infected (x_i)
Primary infections	100	8	100	15	100	25
Secondary infections	800	64	1500	225	2500	625
Tertiary infections	6400	512	22 500	3375	62 500	15 625
Quaternary infections	51 200	4096	337 500	50 625	1 562 500	390 625
Aggregate infections	58 500	4681	361 600	54 241	1 627 600	406 901

α=Transmission rate of infection.

ascertain a loss of productivity valued at $1140 per person quarantined.

Table 3 illustrates the economic effect of quarantining individuals at various stages throughout the epidemic. The number of quarantined individuals and averted infections were calculated using the previous tables, which illustrate the progression of an unchecked epidemic. The number of averted infections was calculated by subtracting the number of infected individuals before quarantine from the maximum number of people potentially infected without intervention.

In order to calculate the net savings as a result of implementing quarantine, we estimated the cost of one person contracting the infection and compared this with the impact of quarantining this index case. The financial consequences of not quarantining the infected individual were calculated by evaluating the costs of the virus spreading to the maximum number of people. The costs and savings from implementing quarantine varied depending on when the measure was implemented. An example is illustrated in Table 3 using data from Table 1.

In the primary wave of the epidemic, the index case is identified and isolated. Since $k=100$, 100 contacts are quarantined for 10 days. Of these contacts, eight individuals inevitably contract the infection while under quarantine. The number of averted infections is calculated by subtracting the maximum number of infections, 4681, from the number of actual infections, nine. Using these figures and the costs associated with them, we calculated the total savings from quarantine. The contacts of eight individuals infected by the index case must also be quarantined; this brings the second wave of exposures to 900. Similar calculations can be made for each wave of exposures.

Table 3 illustrates that quarantine is not only a life saving measure but also a cost-saving mechanism. Furthermore, savings are realized regardless of when quarantine is implemented.

Discussion

Our results indicate that quarantine is not only effective at containing newly emerging infectious diseases, but is also cost saving when compared to not implementing a widespread containment mechanism. The implications of these results are potentially far reaching as local and national governments consider the issue of public health preparedness. Because of the ongoing threat of newly emerging infectious disease and bioterrorism, increased attention and resources are being devoted to public health infrastructure and

Table 2 Aggregate costs of epidemic

α	Aggregate number of infections	Aggregate direct costs ($ million)	Aggregate indirect costs ($ million)	Aggregate costs ($ million)
0.08	4 681	48	24	72
0.15	54 241	552	2834	3386
0.25	406 901	4141	21 261	25 402

Table 3 Costs and savings from quarantine, $\alpha = 0.08$

Spread of infection	Number of Ill	Number of contacts quarantined	Number of averted infections	Direct cost of quarantine ($ million)	Indirect cost of quarantine ($ million)	Total cost of quarantine ($ million)	Total savings ($ million)
Primary wave	1	100	4672	12	0.2	12.2	279
Secondary wave	8	900	4608	12	1	13	274
Tertiary wave	64	7400	4096	12	5	17	232

interventions. This is largely because, in the face of an epidemic of highly transmittable infectious disease, modern medicine would be of limited effectiveness if the virus remains unknown as SARS did in its early days. Antiviral drugs and antibiotics would be of little use, and initially, vaccines and prophylaxis would unavailable. The simplest and most effective tool is quarantine.

We acknowledge that it is unlikely that no widespread public health intervention would be taken to contain an epidemic, and our comparisons may seem extreme. However, these two scenarios serve to illustrate what occurred in the early days of the SARS outbreaks in Toronto. Had SARS been identified in the index patient, or even the primary or secondary infections, the city may have been spared the enormous economic burden of disease that descended upon them in 2003. More than a year after the outbreaks began, government officials were still compensating businesses for financial losses incurred as a result of SARS.[23] Alternately, the eventual quarantine of exposed individuals minimized the spread of SARS and spared the city added expenses.

Our model of the spread of SARS is a relatively simple first estimate of the economic effects of epidemic. Whenever possible, we underestimated the costs associated with variables in order to provide conservative approximations for the expense of quarantine.

Furthermore, our analysis was limited to the costs directly associated with illness and quarantine. We did not explore the economic effects of SARS on hospitals that were forced to close to non-SARS patients in order to prevent further spread of the virus. Also, we did not discuss the highly publicized losses incurred by the tourism industry. The indirect costs associated with the SARS virus did not account for the psychological effects of working during such a stressful time in hospitals on healthcare workers. Many healthcare providers were stigmatized and shunned by their communities because they were potentially exposed to SARS.[24] This lasting emotional and psychological cost is impossible to quantify, but should be considered.

Our analysis of the cost of quarantine relies heavily on the effectiveness of contact tracing during an epidemic. The identification of close contacts relies on the imperfect memory of SARS patients to recall exactly those who they encountered during the incubation period of the virus. Contact tracing also relies on people coming forth if they know they have been in contact with a person infected SARS. Based on anecdotal evidence,[25] many feared coming forth about a possible exposure to SARS for fear that they might lose their jobs. Obviously, this process is imperfect, but as is evident from the results of quarantining individuals at various stages in the epidemic, it is better to quarantine a few infectious people than none at all. In the case of the Toronto outbreaks, compliance with quarantine was very high.[26]

Conclusion

Infectious disease researchers and experts worldwide unanimously agree that this not the last time a highly transmittable infectious disease will emerge and spread across the globe.[27] In the words of Dr Alison McGeer, hospital epidemiologist at Toronto's Mount Sinai Hospital, 'We have been warned'.[28] It is highly probable that the next pandemic will be much more contagious and, perhaps, more lethal than SARS. Ultimately, the SARS epidemic in Toronto resulted in relatively few infections and deaths. Had the virus not been contained, it could have spread throughout Canada as well as the rest of the world with much more devastating results.[29] This paper illustrates that it is not only in our humanitarian interest for public health and healthcare officials to remain aggressive in their response to newly emerging infections, it is also in our collective economic interest. Despite somewhat daunting initial costs, quarantine saves both lives and money.

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