Evaluating the Risk of Reopening the Border: A Case Study of Ontario (Canada) to New York (USA) Using Mathematical Modeling

Pei Yuan, Elena Aruffo, Qi Li, Juan Li, Yi Tan, Tingting Zheng, Jummy David, Nick Ogden, Evgenia Gatov, Effie Gournis, Sarah Collier, Beate Sander, Guihong Fan, Jane M. Heffernan, Jun Li, Jude Dzevela Kong, Julien Arino, Jacques Bélair, James Watmough, and Huaiping Zhu

1 Introduction

SARS-CoV-2 can rapidly spread within and between populations. Travel restrictions and border closures have been among the first control measures to be implemented during the COVID-19 pandemic. After several months of lockdown, regional economic outcomes have suffered greatly [1]. Borders have therefore begun to be

Supplementary Information The online version contains supplementary material available at (https://doi.org/10.1007/978-3-030-85053-1_14).

Pei Yuan, Elena Aruffo, Qi Li and Juan Li contributed equally.

P. Yuan · E. Aruffo · Y. Tan · J. David · J. M. Heffernan · J. D. Kong · H. Zhu (✉)
Funding: This research was supported by the Canadian Institutes of Health Research, Canadian COVID-19 Math Modelling Task Force and the Natural Sciences and Engineering Research Council of Canada, Toronto, ON, Canada
e-mail: yuanpei@yorku.ca; aruffoe@yorku.ca; lbxty@yorku.ca; jummy30@yorku.ca; jmheffer@yorku.ca; jdkong@yorku.ca; julien.arino@umanitoba.ca; belair@dms.umontreal.ca; watmough@unb.ca; huaiping@yorku.ca

Q. Li
Shanghai Normal University, Shanghai, China
e-mail: 1000443603@smail.shnu.edu.cn

J. Li
Shanxi University, Taiyuan, China
e-mail: lijuanjuan0120@163.com

T. Zheng
Xingjiang University,Ürümqi, China
e-mail: ztt0711@163.com

V. K. Murty, J. Wu (eds.), *Mathematics of Public Health*, Fields Institute Communications 85, https://doi.org/10.1007/978-3-030-85053-1_14

reopened to allow the growth of local economies, but to do so, changes to safety measures, such as COVID-19 tests, health certificates, and quarantine requirements [2–5], to keep the importation of cases and possible spread of infection in destination regions under control.

While reopening borders will help relaunch local and global economies, a complete and uncontrolled opening can result in new waves of outbreaks. More locally, Prince Edward Island (Canada) experienced a new cluster of COVID-19 cases stemmed from a traveler from the USA [6]. Infected travelers are key to the global spread of COVID-19 [7–10]. Therefore, the critical question is if there is a way to reopen borders but ensuring minimal COVID-19 spread risk.

There has been an enormous amount of trade and transportation across the Canada-USA land border. On average, more than 70,000 trucks and 700,000 people crossed the Buffalo-Niagara Falls border each month in 2019 [11]. Between January to June 2020 there were only 744,489 overnight visitors into Ontario from the USA (4136 per day), a 73.7% decrease compared to the same period in 2019 (15,698 per day). Overnight overseas visitors also dropped [12] (by 71.3%). Simultaneously, Ontario's hotel occupancy rate dropped by 31.1% (from 65.4% to 34.3%), and

N. Ogden
Public Health Agency of Canada, Ottawa, ON, Canada
e-mail: nicholas.ogden@canada.ca

E. Gatov · E. Gournis · S. Collier
Toronto Public Health, Toronto, ON, Canada
e-mail: evgenia.gatov@toronto.ca; jenny.gatov@mail.utoronto.ca; effie.gournis@toronto.ca; sarah.collier@toronto.ca

B. Sander
Dalla Lana School of Public Health, University of Toronto, Toronto, ON, Canada
e-mail: beate.sander@uhnresearch.ca

G. Fan
Columbus State University, Columbus, GA, USA
e-mail: fan_guihong@columbusstate.edu

J. Li
Xidian University, Xi'an, China
e-mail: lijun@xidian.edu.cn

J. Arino
Department of Mathematics, University of Manitoba, Winnipeg, MB, Canada
e-mail: Julien.Arino@umanitoba.ca

J. Bélair
Université de Montréal, Montreal, QC, Canada
e-mail: belair@dms.umontreal.ca

J. Watmough
University of New Brunswick, Fredericton, NB, Canada
e-mail: watmough@unb.ca

revenue per available room dropped by 55.6% [12]. Although no direct data show the specific losses caused by the border closure, open borders play a crucial role in both economic and social lifelines. However, the USA's situation is very worrying, with 6,656,799 cumulative cases on September 18, 2020 and currently about 40,000 new cases per day [13]. Thus, a reopening of the Canada-USA border requires careful consideration. Now the border is still closed [14, 15], if and when to reopen made frequent headlines of both countries.

Some studies have confirmed that border closure has played a crucial role in delaying and controlling the advancement of COVID-19 [16–25] Dickens et al. [16] showed that effective testing and a mandatory 14-day quarantine of all travelers into Canada are needed to curb COVID-19 if the border is reopened. Linka et al. [17], however, suggested a complete travel ban.

Another COVID-19 restrictive measure that has been implemented is the stay-at-home policy (SAHP). SAHP is effective in controlling the spread of the infection [26, 27] in concert with border closures. Ontario entered phase three with community reopening at the end of July, and while transmission has been kept under control, recently, there is evidence that the epidemic is resurging [28]. If borders are reopened, it may increase epidemic resurgence in Canada beyond our capacity to control.

Given the extensive land border between Canada and the USA, it is essential to investigate the impact of a full/partial reopening of the border on the spread of COVID-19 in Canada. Herewith we present a compartmental mathematical SEAIR model (following the Susceptible-Exposed-Asymptomatic-Infectious (prodromal phase)-Infectious (with symptoms)-Recovered) that is employed to quantify different border reopening strategies. Using the household structure model for Toronto, we will incorporate daily travelers, traveler quarantine policy, and border testing or required health certificates. We define an average risk index to forecast the intensity of COVID-19. Investigating the effective reproduction number and forecasting simulations is also carried out to inform public health decision-makers on the best border reopening strategies that will contain the spread of the epidemic.

2 Method

2.1 Data and Materials

Canada and the USA share the longest land border in the world. However, we focus only on investigating visitors from USA to Canada from the border of Ontario and New York State given the large number of vehicles crossing the border [29], and consider the extreme case that visitors all enter Toronto as a worst scenario of increasing incoming travelers after border reopens. We obtained daily new confirmed case data, by episode date and reporting date in Toronto from February 24, 2020, to August 31, 2020 [28]. This data is used to validate our model during escalation (February 24–mid-March), mitigation (mid-March–mid-May), and de-escalation (stage 1: mid-May–mid-June, stage 2: mid-June–mid-July, stage 3: mid-July to border reopening) stages of the epidemic before border reopening, and to evaluate the risk of transmission in Toronto over time. The model validation results are presented in Figure ESMC1 in the electronic supplementary material (ESM C).

2.2 Compartmental Model: Description and Assumptions

The federal government of Canada determines entry into Canada. Therefore, the federal government decides border control measures, whereas what happens after an individual has been granted access into the country is determined by provincial governments. To control case-importation, and consequently, a rapid spread of COVID-19 in Ontario, we assume that the Ontario will implement safety measures for border reopening, applicable at the border upon arrival once travelers are granted entry into the country. We assume that upon arrival at the frontier, traveler health certificates (with an issue date that does not exceed 2 days prior arrival) will be required and that COVID-19 symptom detection checks (i.e., temperature testing) will be implemented. We also assume that all eligible travelers entering Canada will need to provide proof of domicile and a 14-day quarantine plan. Moreover, they must follow all local control policies, i.e., Nonpharmaceutical Interventions (NPIs), personal protective equipment (PPE) requirements, and social distancing restrictions. Modeling assumptions are summarized in Table 1 (Appendix).

We extend our household-based transmission model with a Susceptible-Exposed-Asymptomatic-Infectious (prodromal phase)-Infectious (with symptoms)-Recovered framework proposed in [27] by assuming that a proportion of S, E, A and I (prodromal stage) (m_S, m_E, m_A, m_{I_1}, respectively) travelers will be allowed to cross the border. We note that individuals with positive tests will not cross the border. We do, however, allow for faulty testing, and assumed that the effective detection rate of asymptomatic infections via testing is η.

The model is structured over three periods: before and after implementing SAHP, and after border reopening. In the latter two periods, the population is divided into SAHP (home quarantine) compliant and non-compliant subpopulations, with subscript q and g, respectively.

For travelers, they are divided into quarantined and community. A proportion ω of travelers will be considered part of the community, since not all travelers will strictly respect the mandatory quarantine/isolation policies. Consequently, a proportion $1 - \omega$ will be in the quarantined household sub-group.

Figure 1 shows the flow diagram for modeling [27]. Details of model derivation are in electronic supplementary materials (ESM A).

Given the current epidemics in Canada [30], the planned reopening scheduled on October 21 is improbable. Using available data, we simulate the impact of reopening on Toronto if the border reopened on September 21, 2020 [31]. We will calculate and present useful information to public health on safe reopening once the daily

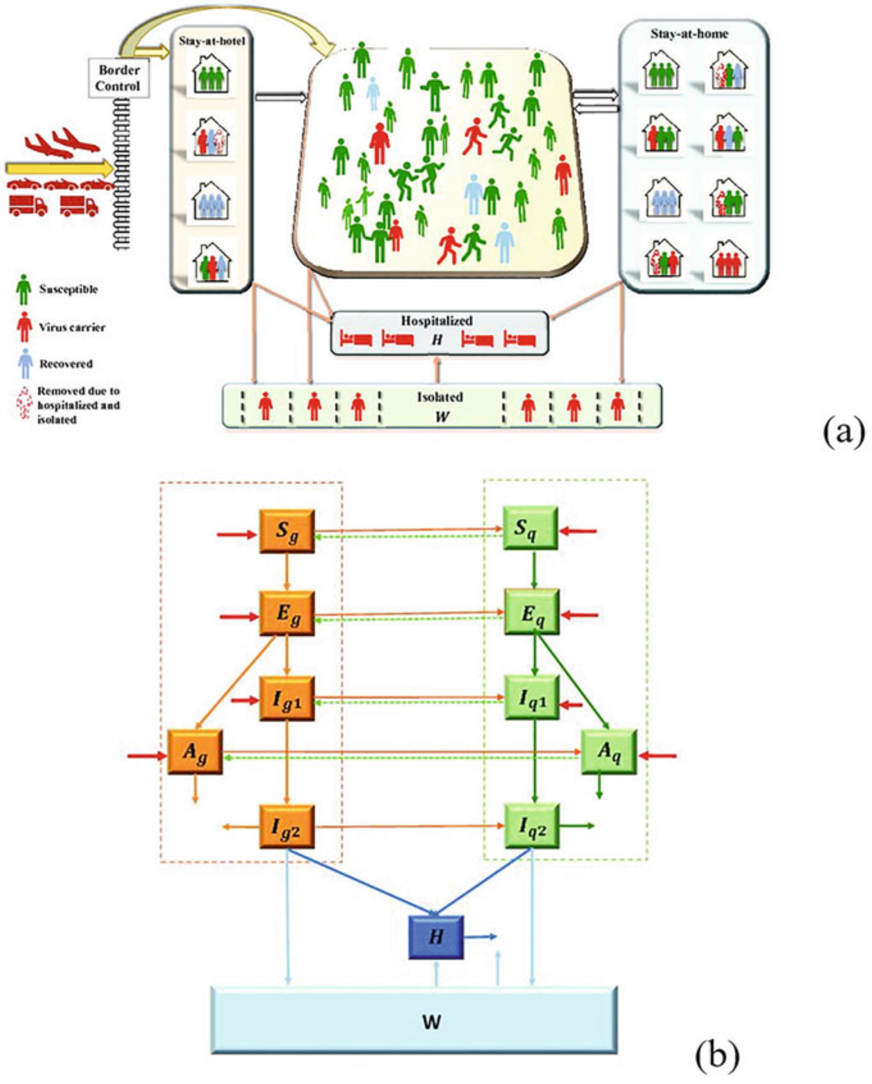

Fig. 1 Modeling with household structure. (**a**) shows the activity and response of different groups. (**b**) Schematic diagram after border reopening, red solid arrow indicates of importation of travelers into quarantined (q) or non-quarantine into Ontario (assuming that they all go to Toronto). Solid lines indicate movement between classes. Dashed lines represent the virus transmission routes

cases in Ontario drop below 100. We will also forecast the infection trend for 1, 12, and 24 weeks after this date. The degree of infection is compared between different strategies, considering variations in the number of daily travelers crossing the border, and variations in parameter for the effectiveness of border control, the ratio of individuals who will go to the non-quarantined group after arrival.

2.3 *Risk Indicators of the Border Opening*

2.3.1 The Instantaneous Reproduction Number

The instantaneous reproduction number, R_t,is defined as

$$R_t = \frac{I_t}{\sum_{j=1}^{t} p_j I_{t-j}}, \tag{1}$$

which can be estimated by the statistical approach [32] using episode date [28]. Here I_t is the new cases on day t and p_j is the discretized distribution of the serial intervals, assuming a Gamma distributed serial interval of 7.5 days with a standard deviation of 3.4 days [33].

2.3.2 Risk Indicator

We define a risk indicator at time t as

$$Risk_t = PercentRank\left(new\ infection_t\right) * 100 \tag{2}$$

indicating the risk of COVID-19 infection on a given day t. Estimation of $Risk_t$ is computed by calculating the rank of the percentile of daily new infections in R [34], indicating the value below which a given percentage of observations is contained. The risk is measured by a function PercentRank, given the relative rank of the number of new infections on a given day in the historical data. A percentage representing those is less than or equal to the value. A non-parametric approach is used in which data do not follow a particular distribution, and the highest and lowest values are excluded. This indicator reflects the degree of risk compared to the current epidemic period since the first wave of the Toronto epidemic peaked in April. A value close to 100 indicates that a new peak of the epidemic has appeared. Also, we define low risk if $0<Risk_t\leq30$, moderate risk if $30<Risk_t\leq50$, high risk if $Risk_t>50$. The risk indicator has also been used in other fields, like in microbiological control levels [35]. It is applicable to inform the public about the risk of COVID using this risk indicator.

3 Results

3.1 *Risk in Toronto*

Figure 2 plots the risk indicator $Risk_t$ for different stages of escalation, mitigation, and de-escalation. We observe that in the 2 weeks before stage 1 reopening was

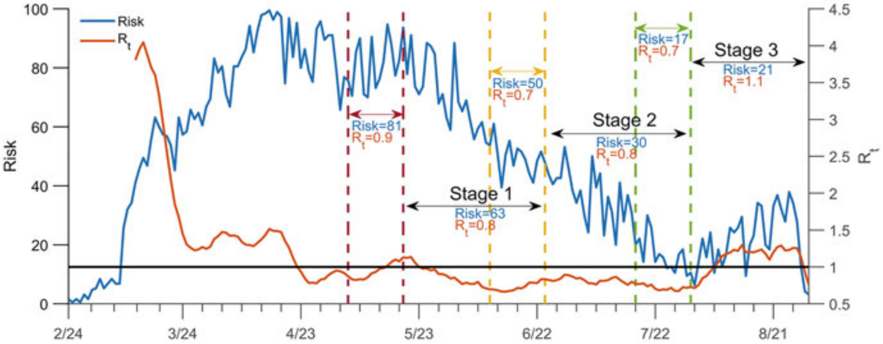

Fig. 2 Risk of COVID-19 in Toronto. Risk indicator in Toronto from February 24 to August 31. The average risk and R_t 2 weeks before and in the period of reopening stage 1, 2 and 3 are presented. The dark solid line indicates the critical threshold $R_t = 1$ of the instantaneous reproduction number. All dates are in 2020

implemented, the risk indicator is very high (Risk = 81) but the average R_t has declined to 0.9. Within the 2 weeks before stage 2 reopening, the average risk has decreased to 50, with $R_t = 0.7$. Finally, before Toronto entered stage 3, the risk dropped to 17 with $R_t = 0.7$. Although the effective reproduction numbers before each reopening stage are below 1, the epidemic risk is entirely different. We also note that the R_t increases to values greater than 1 in stage 3, but the risk value is not high [21].

3.2 Effect of Border Control Measures

Border control will affect the epidemic in two ways: managing the number of people allowed to cross the border and controlling what travelers do after crossing. Figure 3 shows that 1500 daily travelers will generate a sufficient number of infections to cause a new transmission wave, which will be more severe than the first wave. Observe that if the quarantine policy is strictly followed by all travelers (Fig. 3a, b), the daily new cases increase until December 31 and slightly decrease by April 30, 2021 (panel A). We also see that the number of new infections that enter the region does not differ significantly between a 50 or 100% detection level. By April 30 there is only a 5000 person difference in the cumulative number of imported cases (panel B). If 100% of all travelers quarantined upon entering, the level of government resources invested in health certificate checking and temperature testing is not over burdensome. However, we observe a similar outcome when the detection rate is

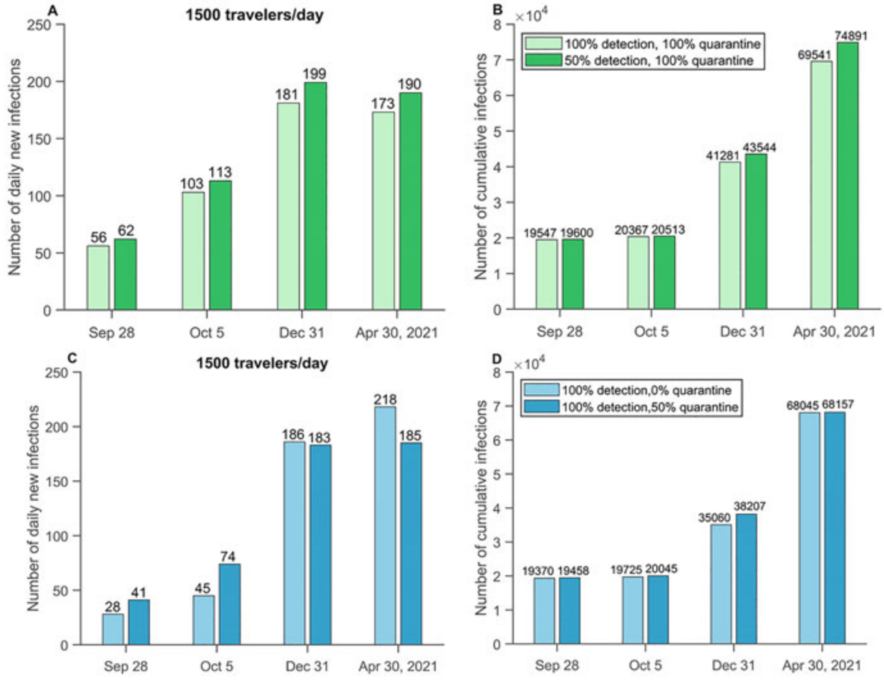

Fig. 3 Effect of border control measures. (top row) Number of daily new infections (**a**) and cumulative infection (**b**) in Toronto 1 week after border reopening (September 28, 2020) to the end of April 2021 for 1500 travelers, when $\omega = 0$ and $\eta = 1, 0.5$. (bottom row) Number of daily new infections (**c**) and cumulative infection (**d**) in Toronto 1 week after border reopening (September 28, 2020) to the end of April 2021 for 1500 travelers daily, when $\eta = 1$ and $\omega = 1, 0.5$. $\omega =$ proportion of travelers not following home quarantine orders. $\eta =$ effective detection rate of asymptomatic infections

100% in detecting possible infection importation (panels C and D)—the difference between the cumulative number of infections given a 0–50% quarantine uptake rate is miniscule (panel D). We note that the results shown in Fig. 3 may not reflect government investment optimization and may instead solely indicated that daily 1500 travelers might overwhelm the system. Both scenarios have been investigated with fewer daily travelers (500 or 1000) in electronic supplementary material (ESM C) (see Fig. ESMC2-C3). While the number of daily and the cumulative number of infections are reduced, we find a similar outcome when comparing detection levels and quarantine rates.

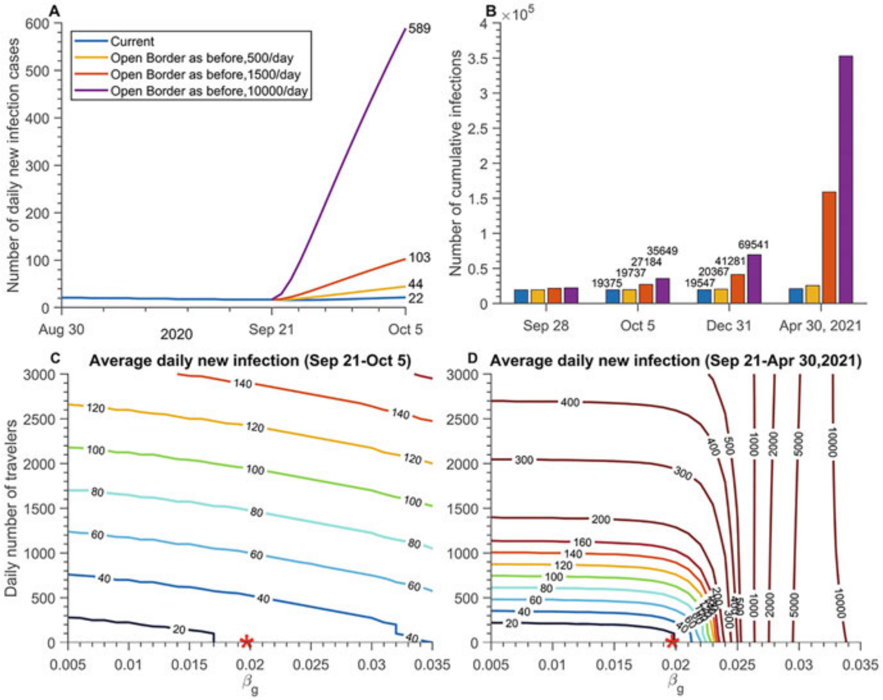

Fig. 4 Effect of importation of travelers. Number of daily new infections (**a**) and number of cumulative infections with different daily number of travelers (0 (border closed), 500, 1500, 10,000 (the situation before pandemic)) under the best border control measures, $\omega = 0$, $\eta = 1$. Contour plot of average daily new infections after border reopening (**c**) within 2 weeks (September 21–October 5) and (**d**) in the long run (September 21, 2020–April 30, 2021) with different daily number of travelers and β_g. The red star indicates the current state in Toronto ($\beta_g = 0.019$). ω= proportion of travelers not following home quarantine orders. η= effective detection rate of asymptomatic infections. β_g= probability of transmission per contact outside household

3.3 Effect of Importation of Travelers

The number of infection cases will increase over time when 500, 1500 or 10,000 (86% of 2019) travelers cross the border daily under perfect conditions that all are quarantined, and the test efficacy is 100% (Fig.4a, b). It is visible that if more than 1500 travelers cross the border daily, the number of infections increases sharply between December 2020 and April 2021. Moreover, if 10,000 travelers are entering Ontario daily, the epidemic will become much severer with daily reported cases over 600 in October that keeps increasing after that. We also observe that opening the border to 500 travelers daily (yellow) does not result in a large outbreak, but the cases are still rising if compared to the current situation.

The number of daily new cases decreases as the number of daily travelers and the probability of transmission outside household (β_g) decreases in the short and long term (Fig. 4c, d). With the current NPIs policy (β_g= 1.9%), an average of 100 or less daily new infections 2 weeks after border reopening are possible if a maximum of 2000 travelers enter Ontario. It will also happen if the current restrictions are lifted (increasing the value of β_g). However, in the long run (until the end of April 2021, Fig. 4d), the daily number of travelers should be restricted to 1000 to keep the average daily new infection below 100 under current NPIs interventions. And if NPIs are relaxed a little (β_g larger than 2.3%), daily cases will exceed 100 if daily number of travelers is above 200. Moreover, Toronto might experience 10,000 daily newly reported cases with relaxed NPIs if borders are opened for an extended period.

3.4 Tradeoff Between Border Reopening and Local Risk

If we open the border for more to enter Canada (represented by Ontario here), we will face increasing local transmission (Fig. 5). Currently, the risk in Toronto (blue star, Fig. 5) is high, we find that to mitigate the risk (in the interval (0–30)), we can only allow about 100 travelers to enter Ontario each day. If more than 300 people cross the border, the average risk will become medium (between 30 and 50), and if more than 1200 travelers to enter, the risk will become high (above 50). We also observe that if the risk in Toronto increases above 30, the average risk will always be medium or high, even just a few travelers to cross the border. On the other hand, if the local risk is relatively low, the average risk remains low if we allow a maximum of daily 500 travelers to cross the border.

4 Discussion

Our findings suggest that the border may be reopened with the restricted number of travelers, under the strictest border control measures when the daily cases in Ontario is roughly 100. Despite that, the risk of local transmission will rise. Hence reopening is imprudent given the current arising situation. Effective detection of infectious visitors at the border and quarantine of passengers after entry can reduce the risk of reopening to a certain extent.

However, we also observe that, in the absence of efficient border control measures and quarantine of travelers, reopening the border might induce a new local outbreak even with a low number of visitors. Moreover, the current local risk is still at a critical point of resurgence and, a slight relaxation of the current

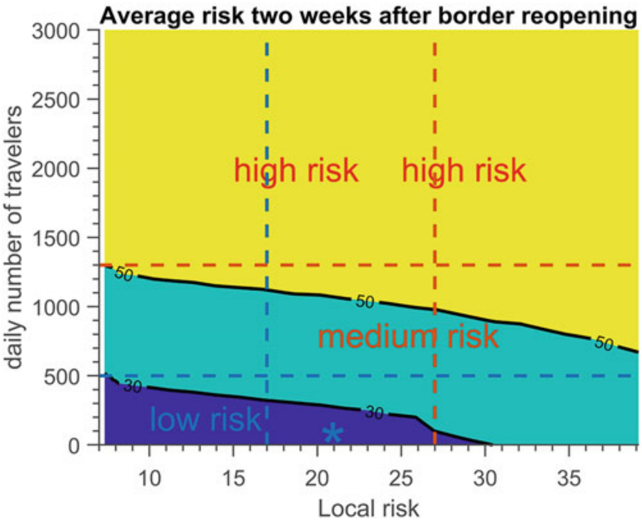

Fig. 5 The tradeoff between border reopening and local risk. Contour plot of average risk in the period of 2 weeks after border reopening on September 21 with different daily number of travelers and local risk. The blue star is the current state.

control measures may result in a new wave of outbreak. Without strengthening local prevention and control measures, it would be even more impractical to reopen the border. Also, even with perfect control measures (efficient testing process at the border and strict implementation of quarantine), if a larger number of passengers, for example, 10,000 per day, to enter Ontario, it will result in a second wave at least three times larger than the original COVID-19 wave in Toronto.

Reasonable and effective risk measurement indicators are crucial for short-term risk forecasting and timely adjustment of staggered measures, especially when it is foreseen that SARS-CoV-2 may persist for a long time. When the instantaneous reproduction number R_t becomes less than 1, we will consider that the local epidemic is well mitigated or controlled. However, when considering border reopening, it is not enough to judge the situation of the epidemic from R_t alone, since we noticed that during the first phase of Toronto's reopening, R_t was already less than 1, but the local infection risk was still high. To ensure more accurate short-term predictions, we consider both R_t and risk indicators as a measurement of infection levels.

In the short run, our new indicator of risk of infection has been useful to establish different levels of risk: low, medium and high. We identified that the current risk in Toronto is low and, in case of reopening, this level can be maintained only if the local risk is below 30 and at most 500 travelers can cross the border. Allowing more people to enter Ontario will result in an increase of the general risk of infection in the province. Hence, we recommend keeping the level of risk low in Ontario, using NPIs, and reopening the border to a minimal number of travelers.

We mainly discuss the number of passengers allowed to enter if the border reopens and local risk. Our results should be interpreted as the best-case scenario indicating the maximum possible number allowed after border reopening. However, neither the effectiveness of border detection nor compliance of individuals coming from abroad with quarantine can be fully guaranteed. People may get upset with social distancing and other control measures, and children have started returning to school in early September, which makes local epidemic prevention and controls more difficult. Therefore, keeping the border closed might be a more appropriate and safer choice. Reopening the border might be a feasible plan when a vaccine is available.

Our work provides an essential reference for public health, it has some limitations. Scenario analyses are conducted under the current epidemic situation in USA. However, it is not very likely that the epidemic in USA will mitigate sooner. If the USA epidemic were to become controlled, our results would need to be re-examined. Moreover, our findings may be too pessimistic for lifting travel restrictions towards countries where the epidemic is well controlled, such as South Korea and China.

In conclusion, reopening the borders to the USA is possible only if the mandatory quarantine, high efficiency of testing at the frontier and a maximum daily number of 500 travelers to cross, if the use of NPIs is enforced strictly, or strengthened further and if the daily cases in Canada drop drastically about 100.

Appendix

Table A.1 Model assumptions

General setting	a.	No birth, death or immigration
	b.	We divide the population into two groups: one consisting of individuals who follows SAHP (indicated by subscript q) and another consisting of individuals who do not opt for this intervention (subscript g). Due to influences of self-protection consciousness and severity of the epidemic, people are assumed to move from one group to another with stay-at-home rate (denoted by $q(t)$) or going out rate (denoted by $g(t)$)
	c.	Each subpopulation is further the divided into Susceptible ($S_i(t)$), Exposed ($E_i(t)$), Asymptomatic (subclinical) infection ($A_i(t)$), Infectious pre-symptomatic (will eventually show symptoms) ($I_{i1}(t)$) and Infectious symptomatic ($I_{i2}(t)$)
	d.	Both $A_i(t)$ and $I_{i1}(t)$ are infectious virus carriers. Individuals in $A_i(t)$ never show symptoms, while individuals in $I_{i1}(t)$ develop into symptomatic classes ($I_{i2}(t)$) after a specified period of time

(continued)

Table A.1 (continued)

	e.	Mild symptomatic infections ($I_{i2}(t)$), may choose to either isolate themselves at home (or other places). If the quarantine is respected well enough, these infections are fully isolated and, consequently, do not contribute to the spread of the virus. Otherwise, they are still a source of infection until recovery
	f.	Two further compartments encode for severe infections: the fully isolated $W(t)$, and the hospitalized H(t) who are all severely affected. Neither of these compartments contribute to infection transmission
Household structure setting	a.	All households contain n ($n = 3$) individuals and family members are homogeneously mixing i.e., contacting each other randomly
	b.	The infection rate of asymptomatic and symptomatic infectious individuals to the susceptible is the same among the household
	c.	Two members in a family cannot be infected by one household member at the same time t
	d.	Every family except for those with symptomatic members has an equal opportunity to be released from quarantine after the SAHP is relaxed
	e.	Households with infected symptomatic individuals will continue to be quarantined after the SAHP is relaxed
	f.	For family members following SAHP, susceptible $S_q(t)$ are only infected by infectious individuals in the home $A_q(t)$, $I_{q1}(t)$ *or* $I_{q2}(t)$
	g.	When there are no infections in a household, the family is safe and is no longer be involved in the transmission of COVID-19
Assumed border control measures	a.	Travelers are required to provide certificate of health to border control officials. Travelers indicate all the people entering The test must report an issued date which does not exceed 2 days prior arrival. ONLY travelers with negative results are allowed to enter Canada. (Note that this is specific to the Canada-USA border.)
	b.	Further tests, such as rapid test (POC) or temperature check, are implemented to all travelers eligible to enter Canada. ONLY travelers with negative tests will be then allowed to enter Canada. (Note that this is specific to the Canada-USA border.)
	c.	The daily number of travelers is restricted
Assumed traveler restrictions	a.	Travelers eligible to enter Ontario/Canada need to provide proof of domicile. Visitors are only allowed to stay in hotels or isolated in camping areas
	b.	Travelers must follow the local control policies, such as mandatory NPI's, PPE's, and social distancing, etc.

Note: See electronic supplementary material for model details and derivation process

Electronic Supplementary Material

Data 1 (DOCX 468 kb)

References

1. Statistics Canada. Recent development in the Canadian economy, 2020: COVID-19, third edition. 2020. https://www150.statcan.gc.ca/n1/pub/11-626-x/11-626-x2020013-eng.htm (3 August 2020, date last accessed).
2. Etias.Info. The EU Is Reopening Its Borders for Internal Travel. 2020. https://www.etias.info/eu-reopening-borders-internal-travel/ (30 July 2020, date last accessed).
3. McClanahan P. Europe's Patchwork Reopening. The New York Times. 2020. https://www.nytimes.com/2020/06/05/travel/europe-reopening-tourism-covid.html (30 July 2020, date last accessed).
4. Chiew CJ, Li Z, Lee VJ. Reducing onward spread of COVID-19 from imported cases: quarantine and 'stay at home' measures for travelers and returning residents to Singapore. J Travel Med 2020; 27: taaa049.
5. Li X, Liu M, Zhou R, et al. Centralized medical quarantine for imported COVID-19 in Shanghai, China, J Travel Med 2020; 27: taaa109.
6. Silberman A. Canada adds health officials at U.S. border crossings to screen for COVID-19. CBC News. 2020. https://www.cbc.ca/news/canada/new-brunswick/canada-adds-health-officials-us-border-1.5645990 (15 July 2020, date last accessed).
7. Liu JY, Chen TJ, Hwang SJ. Analysis of Imported Cases of COVID-19 in Taiwan: A Nationwide Study. Int J Environ Res Public Health 2020; 17: 3311.
8. Ministry of Health (New Zealand) 3 new imported cases of COVID-19. 2020. https://www.health.govt.nz/news-media/media-releases/3-new-imported-cases-covid-19-1 (10 October 2020, date last accessed).
9. Luft A. Travelers who sat close to COVID-19-infected passenger on Air Canada flight will be alerted: Quebec public health. CTV News. 2020. https://montreal.ctvnews.ca/travellers-who-sat-close-to-covid-19-infected-passenger-on-air-canada-flight-will-be-alerted-quebec-public-health-1.4825506 (1 September 2020, date last accessed).
10. Davidson S. More planes land in Canada with COVID-19-infected passengers. Here's where the flights came from. CTV News. 2020. https://toronto.ctvnews.ca/more-planes-land-in-canada-with-covid-19-infected-passengers-here-s-where-the-flights-came-from-1.5076714 (1 September 2020, date last accessed).
11. Tableau Server. Border Crossing Entry Data. 2020. https://explore.dot.gov/views/BorderCrossingData/Monthly?:isGuestRedirectFromVizportal=y&:embed=y (30 August 2020, date last accessed).
12. Government of Ontario. Tourism research. 2020. http://www.mtc-currentperformance.com (18 Sep 2020, date last accessed).
13. Centers for Disease Control and Prevention. Coronavirus Disease 2019 (COVID-19). 2020. https://www.cdc.gov/coronavirus/2019-ncov/cases-updates/cases-in-us.html (30 July 2020, date last accessed).
14. National Post Staff. Hundreds of thousands of U.S. visitors are still crossing border into Canada each week. National Post News. 2020. https://nationalpost.com/news/hundreds-of-thousands-of-u-s-visitors-are-still-crossing-border-into-canada-each-week (22 July 2020, date last accessed).
15. Government of Canada. Coronavirus disease (COVID-19): Travel restrictions, exemptions and advice. 2020. https://www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection/latest-travel-health-advice.html (29 July 2020, date last accessed).
16. Dickens BL, Koo JR, Lim JT, et al. Strategies at points of entry to reduce importation risk of COVID-19 cases and reopen travel. J Travel Med 2020; taaa141.
17. Linka K, Rahman P, Goriely A, Kuhl E. Is it safe to lift COVID-19 travel bans? The Newfoundland story. Comput Mech 2020; 66: 1081-1092.
18. Hu Z, Cui Q, Han J, et al. Evaluation and prediction of the COVID-19 variations at different input population and quarantine strategies, a case study in Guangdong province, China. Int J Infect Dis 2020; 95: 231-240.

19. Huang Q, Kang YS. Mathematical Modeling of COVID-19 Control and Prevention Based on Immigration Population Data in China: Model Development and Validation. JMIR Public Health Surveill 2020; 6: e18638.
20. Sun T, Weng D. Estimating the effects of asymptomatic and imported patients on COVID-19 epidemic using mathematical modeling. J Med Virol 2020; 92: 1995-2003.
21. Hossain MP, Junus A, Zhu X, et al. The effects of border control and quarantine measures on the spread of COVID-19. Epidemics 2020; 32: 100397.
22. Chinazzi M, Davis JT, Ajelli M, et al. The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. Science 2020; 368: 395-400.
23. Kraemer MG, Yang CY, Gutierrez B, et al. The effect of human mobility and control measures on the COVID-19 epidemic in China. Science 2020; 368: 493-497.
24. Linka K, Peirlink M, Costabal FS, Ellen K. Outbreak dynamics of COVID-19 in Europe and the effect of travel restrictions. Comput Methods Biomech Biomed Engin 2020; 23: 710-717.
25. Song W, Zang P, Ding Z, et al. Massive migration promotes the early spread of COVID-19 in China: a study based on a scale-free network. Infect Dis Poverty 2020; 9:109.
26. Gao S, Rao J, Kang Y, et al. Association of Mobile Phone Location Data Indications of Travel and Stay-at-Home Mandates With COVID-19 Infection Rates in the US. JAMA Netw Open 2020; 3: e2020485.
27. Yuan P, Li J, Aruffo E, et al. Efficacy of 'Stay-at-Home' Policy and Transmission of COVID-19 in Toronto, Canada: A Mathematical Modeling Study. 2020. Available at SSRN: https://doi.org/10.2139/ssrn.3678581
28. City of Toronto. COVID-19. 2020. https://www.toronto.ca/home/covid-19/ (31 Aug 2020, date last accessed).
29. Statistics Canada. Number of vehicles travelling between Canada and the United States. 2020. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2410000201 (22 July 22 2020, date last accessed).
30. Government of Canada. Coronavirus disease (COVID-19). 2020. https://www.canada.ca/en/public-health/services/diseases/coronavirus-disease-covid-19.html (3 August 2020, date last accessed).
31. Government of Canada. Travel restriction to Canada remain in place for September long weekend. 2020. https://www.canada.ca/en/border-services-agency/news/2020/08/travel-restrictions-to-canada-remain-in-place-for-september-long-weekend.html (30 Aug 2020, date last accessed).
32. Cori A, Ferguson NM, Fraser C, et al. A new framework and software to estimate time-varying reproduction numbers during epidemics. Am J Epidemiol 2013; 178: 1505-1512.
33. Li Q, Guan X, Wu P, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. N Engl J Med 2020; 382: 1199–207.
34. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2020. https://www.R-project.org/ (30 July 2020, date last accessed).
35. Gordon O, Goverde M, Pazdan J, et al. Comparison of different calculation approaches for defining microbiological control levels based on historical data. PDA J Pharm Sci Technol 2015; 69: 383-398.