Importation models for travel-related SARS-CoV-2 cases reported in Newfoundland and Labrador during the COVID-19 pandemic

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Abstract

During the COVID-19 pandemic there was substantial variation between countries in the severity of the travel restrictions implemented suggesting a need for better importation models. Data to evaluate the accuracy of importation models is available for the Canadian province of Newfoundland and Labrador (NL; September 2020 to June 2021) as arriving travelers were frequently tested for SARS-CoV-2 and travel-related cases were reported. Travel volume to NL was estimated from flight data, and travel declaration forms completed at entry to Canada, and at entry to NL during the pandemic. We found that during the pandemic travel to NL decreased by 82%, the percentage of travelers arriving from Québec decreased (from 14 to 4%), and from Alberta increased (from 7 to 17%). We derived and validated an epidemiological model predicting the number of travelers testing positive for SARS-CoV-2 after arrival in NL, but found that statistical models with less description of SARS-CoV-2 epidemiology, and with parameters fitted from the validation data more accurately predicted the daily number of travel-related cases reported in NL originating from Canada ($\boldsymbol{R^2 = 0.55}$, $\boldsymbol{\Delta}$AICc = 137). Our results highlight the importance of testing travelers and reporting travel-related cases as these data are needed for importation models to support public health decisions.

Keywords: Importation risk, travel restriction, SARS-CoV-2, Newfoundland and Labrador, travel-related cases, COVID-19, pandemic

Significance: Importation models consider epidemiology and inbound travel volumes to predict the arrival rate of infected travelers to a jurisdiction, and are used to guide travel restriction recommendations during outbreaks. A limitation of many importation models are that they are not validated with 'real world' data. Using data from the province of Newfoundland and Labrador (NL), Canada, we develop an importation model that considers travel volumes estimated from travel declaration forms completed by arriving travelers, and SARS-CoV-2 epidemiology. We validate the model using the number of travel-related cases reported from September 2020 to May 2021 in NL. Our results highlight the importance of reporting travel-related cases, and the need for detailed travel and epidemiological data to formulate reliable importation models.

1 Introduction

On January 31, 2020, due to an outbreak of SARS-CoV-2 in Wuhan, China the World Health Organization (WHO) advised other countries to expect SARS-CoV-2 cases and be prepared for outbreak containment, but travel restrictions were explicitly not recommended (Grépin et al, 2021). Nonetheless, during the initial phase of the COVID-19 pandemic most countries implemented travel restrictions (Grépin et al, 2021; Piccoli et al, 2022; Shoichet, 2020). The next two years of the COVID-19 pandemic would see substantial variation in the implementation and strictness of travel restrictions between (Piccoli et al, 2022) and within countries (Reddy et al, 2021; Studdert et al, 2020). In July 2021, the WHO provided updated recommendations stating that international travel-related measures be 'proportionate to the public health risk' and adapted to a country's 'specific epidemiological, health system and socioeconomic context' (World Health Organization, 2021).

The unprecedented implementation of travel restrictions during the initial phase of the COVID-19 pandemic may have been because COVID-19 is more challenging to detect and contain than H1N1 influenza A (Anderson et al, 2020; Grépin et al, 2021), and the inconsistent implementation of travel restrictions during the first two years of the pandemic may have been due to the low quality of evidence to support policy. Systematic reviews (Burns et al, 2021; Grépin et al, 2021) report that travel restrictions may have had a positive impact on infectious disease outcomes and reduced and delayed imported SARS-CoV-2 cases from Wuhan, but that overall the quality of evidence was low. Most evidence was due to modelling studies with a lack of 'real world' data (Burns et al, 2021), with inconsistent parameter estimates and assumptions, and that overlooked the impact of undetected cases outside of China (Grépin et al, 2021). These shortcomings may have been due to a lack of data and the urgency of the public health emergency.

From May 4, 2020–June 30, 2021, the Canadian province of Newfoundland and Labrador (NL) implemented travel restrictions that required non-residents to complete Travel Declaration Forms (TDFs) and self-isolate for 14 days after arrival (Government of Newfoundland Labrador, 2023). It is likely that a high proportion of SARS-CoV-2 infections were detected in arriving travelers due to mandatory testing for anyone symptomatic, mandatory testing of rotational workers, that is NL residents that work in other provinces, intermittent requirements for some asymptomatic travelers to complete testing, and because there were few community outbreaks of COVID-19 in NL during this time (Hurford et al, 2021). We refer to the number of travel-related cases reported in NL from Canadian and international origins as 'the validation data'.

Several studies have combined air travel volumes, SARS-CoV-2 epidemiology, and infection prevalence at either the traveler's origins or destination to estimate importation risk. Studies found that the Wuhan and China travel ban in early 2020 decreased the number of infections amongst air travelers originating from mainland China and entering other countries (Chinazzi et al, 2020; Wells et al, 2020), and have described the early spread of infection within China (Hossain et al, 2020). Importation modelling has been used to calculate the potential for COVID-19 spread between countries (Nakamura and Managi, 2020), to identify countries expected to have a high percentage of incidence due to importations (Russell et al, 2021), and to determine the effectiveness of post-arrival travel restrictions (Costantino et al, 2020; Yang et al, 2021).

We used three sources of travel volume data from both before and during the COVID-19 pandemic to understand the impacts of Newfoundland and Labrador's travel restrictions on travel volume and traveler's origins, and we develop an epidemiological model to compare with the validation data describing the number of travel-related cases. Other models that have been developed either do not consider travel volumes (Godin et al, 2021; Steyn et al, 2021), do not consider infection prevalence at the destination (Hincapie et al, 2022; Linka et al, 2020; Menkir et al, 2021; Russell et al, 2021), or do not distinguish between travel-related and community cases at the destination (Chinazzi et al, 2020; Costantino et al, 2020; Hossain et al, 2020; Wells et al, 2020), with only Yang et al (2021) having previously considered all of these data types in their analysis determining the impact of post-arrival restrictions in Hong Kong.

2 Methods

2.1 Background

Newfoundland and Labrador (population: 510,550; Statistics Canada 2021) is the second smallest Canadian province. Most non-resident travelers to Newfoundland and Labrador visit the island of Newfoundland (93%, Government of Newfoundland Labrador 2018, population: 483,895 Statistics Canada 2021) and arrive by air to one of only a few ports of entry. Rotational workers, NL residents that work in other provinces, are a significant proportion of the NL workforce (Hewitt et al, 2018), and during the COVID-19 pandemic were subject to specific travel restrictions and testing regimes.

2.2 Travel volume to NL

The travel volume that we estimate is all individuals that arrive in NL from other Canadian provinces, the Canadian territories, or international origins, and might spread infections to the NL community. This 'total travel volume' includes arrivals by air, sea, and land ports of entry, crew members, and NL residents returning from travel. We consider three data sources that report whether the travel was of Canadian or international origin. These are the International Air Transport Authority (IATA; see also Linka et al 2020), Travel Declaration forms (TDF) completed by non-NL residents and other non-exempt individuals upon arrival to NL during the COVID-19 pandemic, and Frontier Counts (FC) (Statistics Canada, 2020-2021) completed at the Canadian border. Each of these data sources provide information on travel volumes from an origin (i.e., not layovers) but for different populations and all with limitations (summarised in table B2).

We combined these data sources and considered reports from the Government of Newfoundland and Labrador (2020-2021) to estimate the total travel volume arriving in NL from January 2019 to March 2020, and September 2020 to May 2021 (equation B1). We estimated the travel volume of regular travelers arriving from each of the Canadian provinces, the Canadian territories, for the United States of America, and for all other international origins by multiplying the total travel volume by the percentage of travelers reported from each of these origins for the IATA and TDF data (equations B4 and B5). We estimated these same quantities for the travel volume of rotational workers (equation B3, also see Appendix B.3.3).

2.3 The infection status of departing travelers

We estimate infection prevalence at the travelers origin from daily incidence in the Canadian provinces and territories as reported by the Public Health Agency of Canada (equation C6). These estimates include adjustments for reporting delays and are multiplied by a coefficient describing under-reporting in each of these regions based on seroprevalence data reported by the COVID Immunity TaskForce. We assume that the exposure date of infected travelers is uniformly distributed between 0 and 13 days prior to departure. Date of first symptom onset and Polymerase Chain Reaction (PCR) test sensitivity depends on the number of days since exposure. We assume that a fraction of travelers originating from Canada and internationally, and all travelers that test positive on pre-departure tests (see table D8) do not travel (equation C12).

2.4 Post-arrival testing in NL

Travelers need to test positive for SARS-CoV-2 in NL to be reported as travel-related cases. Table D8 summarizes testing requirements for travelers arriving in NL, with different requirements applying to rotational workers and regular travelers that develop symptoms while completing 14 days of self-isolation. The number of travel-related cases reported in NL from international origins and Canadian origins is predicted by equations D21 and D22, respectively. We refer to the model described in sections 2.3-2.4 as the 'epidemiological model' because it is an importation model based on the SARS-CoV-2 epidemiology and the travel restrictions that occurred in NL at the time. Additional details of this model are provided in the Appendices A, C, and D.

2.5 Statistical importation models and validation

We validate the epidemiological model (equations D21 and D22) using daily travel-related cases of Canadian and international origin (Figure F3B). Approaches to modelling importations vary, but frequently models consider travel volume, infection prevalence at travel origins, and the product of both summed over all possible origins. To explore what variables and level of epidemiological detail are needed to predict the daily travel-related cases from Canadian or international origins reported in NL (September 2020 - May 2021), we consider several statistical models with parameters estimated from the validation data. Explanatory variables were daily travel volume, daily infection prevalence, the product of daily travel volume and infection prevalence, and we considered these variables for each non-NL province and the Canadian territories (all three combined), and all of Canada (9 non-NL provinces and the territories combined).

3 Results

We found that the total travel volume arriving in NL declined by 82% during the pandemic while travel restrictions were enacted (September 2020 to May 2021) compared to the same period a year prior (figure 1A; red line). During the pandemic the percentage of travelers arriving in NL from different origins also changed (figure 2). Relative to the same 9 months one year prior to the pandemic, the average percentage of travelers arriving in NL increased from British Columbia (2.5 to 5.5%), Alberta (7 to 17%), the Canadian territories (0.3 to 3.3%), and international origins not the United States (8 to 15%; figure 2). The average percentage of travelers arriving in NL during the pandemic decreased from Ontario (27 to 21%), Québec (14 to 4%) and the United States (14 to 8%; figure 2).

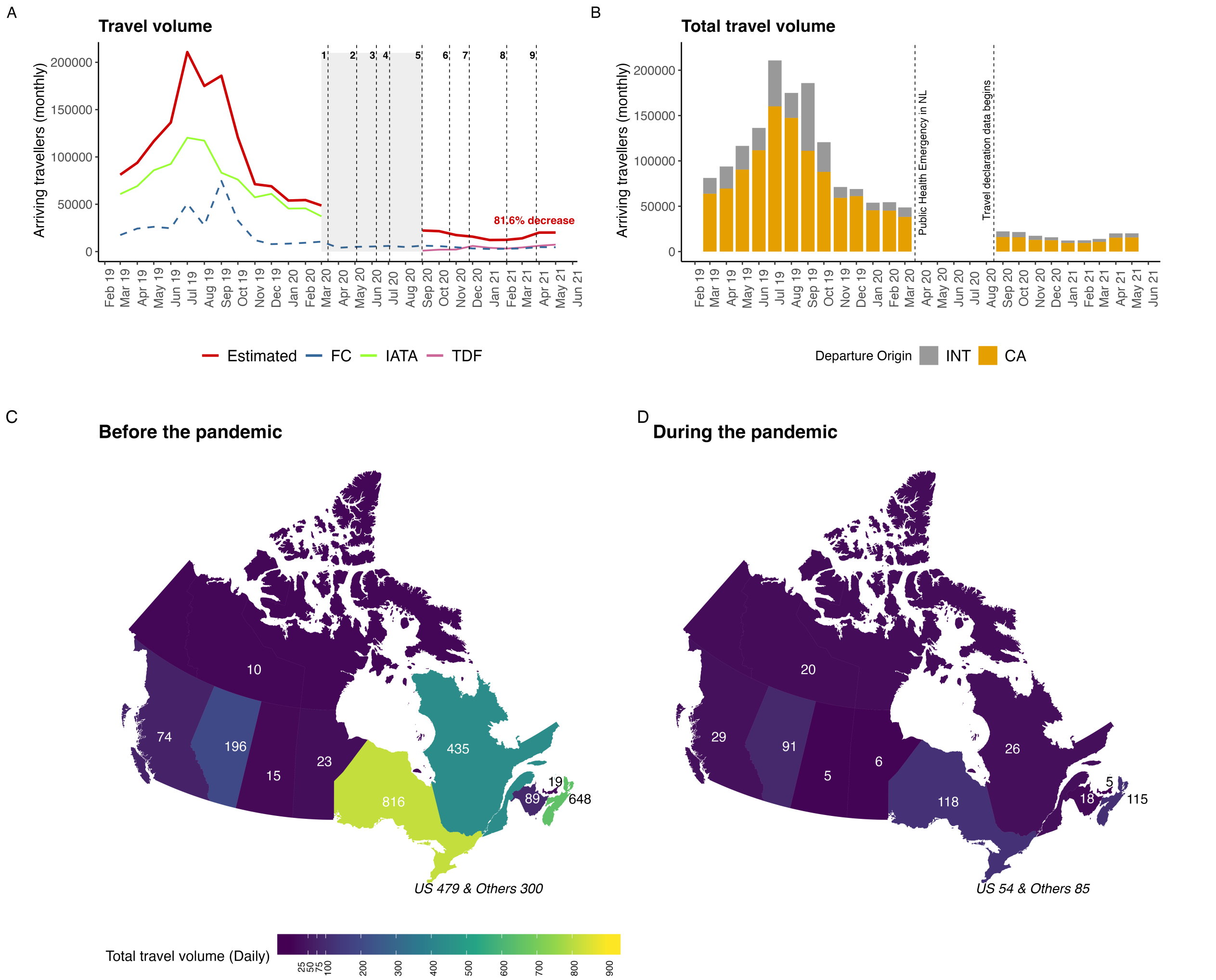

Fig. 1 A) The total travel volume arriving in Newfoundland and Labrador before and during the pandemic. The red line ($V_{\text{CA}} + V_{\text{INT}}$ equation B1) shows the estimated total travel volume while the other lines are the reported travel volume from different data sources (Green: International Air Transport Authority (IATA), Purple: Travel Declaration Forms (TDF), Blue: Frontier Counts (FC)). The numbered vertical lines correspond to travel restrictions implemented in NL (see B4). B) Total travel volume arriving from Canadian and international origins. C) and D) The average number of travelers arriving daily before and during the pandemic and their region of origin, where these averages are taken over 9 months.

We compared our epidemiological model (figure 3C,D; blue bars) to travel-related cases reported to the Newfoundland and Labrador Centre for Health Information (figure 3C,D; lines). These same data were also reported publicly in Public Service Announcements from the Newfoundland and Labrador government. Using corrected

Akaike Information Criteria (AICc) we found that travel-related cases arriving to NL from Canada was best predicted by a statistical model with explanatory variables that were daily travel volume multiplied by daily infection prevalence for each of the provinces of Canada and the Canadian territories ($R^2 = 0.551$; table 1; figure 3). Our epidemiological model was the lowest ranked model (ΔAICc = 137, $R^2 = 0.155$; table 1) for travel-related cases originating in Canada. The poor performance of the epidemiological model is due to under-estimating the number of travel-related cases originating from Canada, particularly in April and May 2021 (figure 3C).

All of the models we considered were inadequate to predict travel-related cases arriving to NL from international origins (R^2 <0.06, table 1). This is likely because few travel-related cases of international origin were reported (less than 20 per month, figure 3D, grey line), and because we assumed that the infection prevalence globally was equal to that of the United States owing to inconsistent reporting of infections between countries.

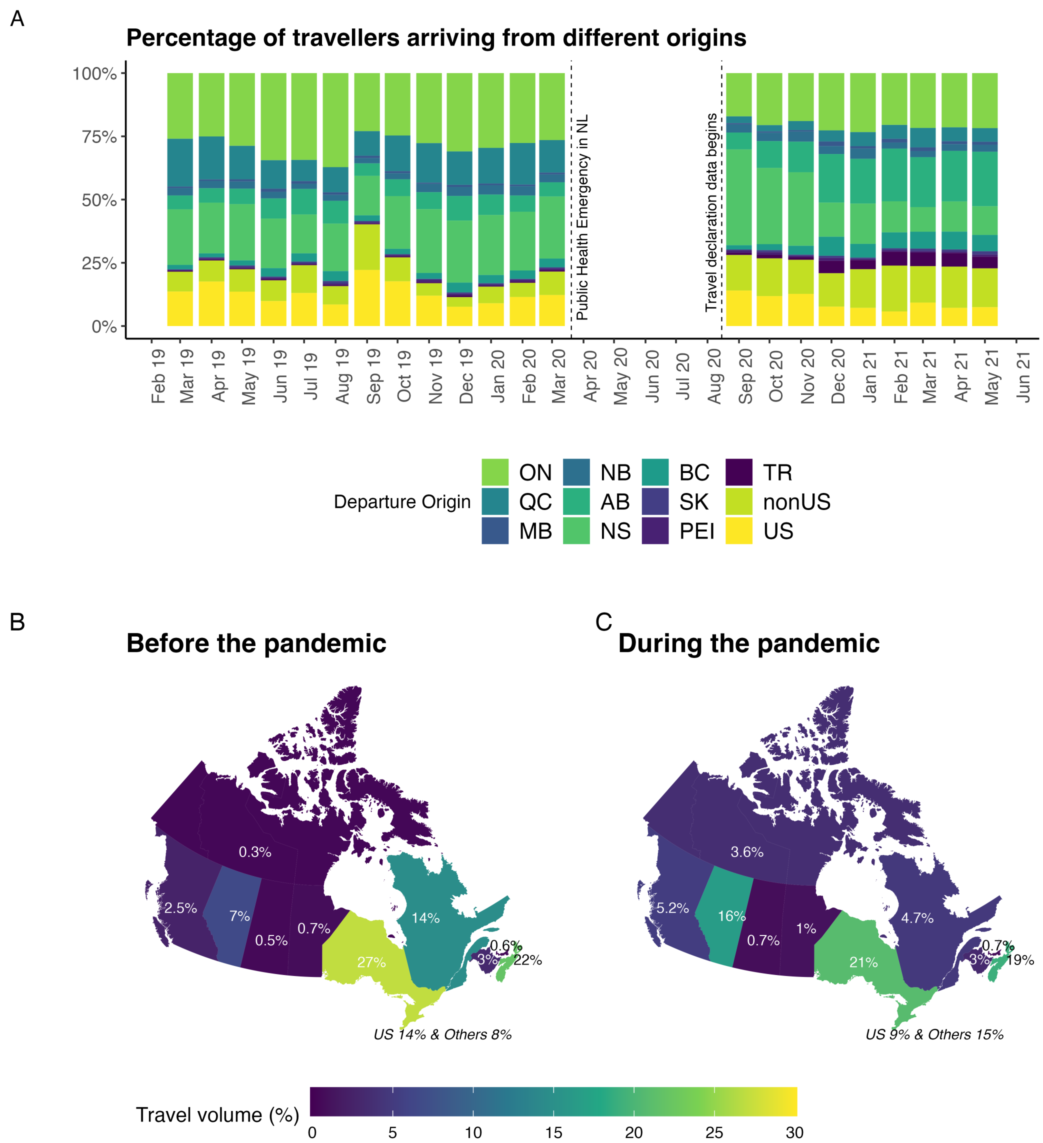

Fig. 2 Effect of the pandemic on the percentage of travelers arriving in NL from different origins. A) The percentage of travel volume each month from each of the 9 non-NL Canadian provinces, the Canadian territories (TR is all three territories combined), the United States, and non-United States international origins. B) The average percentage of arrivals from particular origins for 9 months during the pandemic (September 2019 to March 2020, and April to May 2019) and C) this same average for the same 9 months during the pandemic (September 2020 to May 2021).

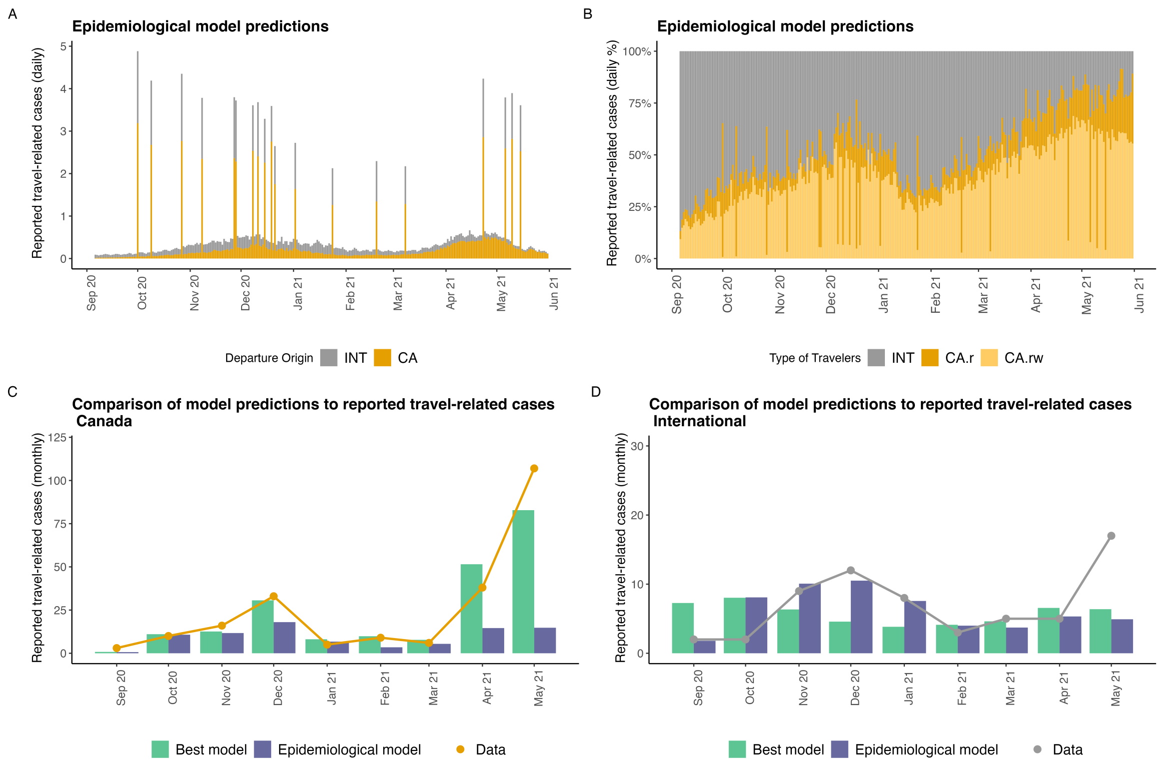

Fig. 3 A) Daily reported travel-related cases as predicted by the epidemiological model for travelers arriving from Canadian (CA) and International (INT) origins. B) Daily percentage of reported cases as predicted by the epidemiological model that are from Canadian origins: both regular travelers (CA.r, dark yellow) and rotational workers (CA.rw, light yellow), and from international origins (grey). The predicted reported travel-related cases arriving in NL (monthly) for the epidemiological model (blue bars) and the best model (green bars; see table 1) for travelers originating from (C) Canadian and (D) international origins. In both, C and D monthly travel-related cases reported in NL are shown with lines. The results shown in panels C) and D) but as predicted daily travel-related cases are shown in figure E2.

Table 1 Model selection for predicted daily travel-related cases reported in NL from Canadian and international origins.

	Canada	K	AICc	Δ AICc	LL	R^2
1	Travel volume × Infection prevalence (Provinces)	11	889.1	0.00	-433.0	0.551
2	Infection prevalence (Provinces)	11	921.2	32.09	-449.1	0.495
3	Travel volume (Provinces)	11	946.4	57.3	-461.7	0.446
4	Travel volume × Infection prevalence (Canada)	2	990.4	101.4	-493.2	0.302
5	Travel volume (Canada)	2	1005.4	116.4	-500.7	0.262
6	Infection prevalence (Canada)	2	1008.0	118.9	-502.0	0.256
7	Epidemiological model (Canada)	1	1026.0	136.9	-512.0	0.156
	International					
1	Travel volume (International)	2	676.6	0.00	-336.3	0.056
2	Infection prevalence (International)	2	677.9	1.28	-336.9	0.052
3	Travel volume × Infection prevalence (International)	2	679.1	2.52	-337.6	0.048
4	Epidemiological model (International)	1	683.5	6.8	-340.7	0.003

4 Discussion

We estimated that travel restrictions reduced the total travel volume arriving in NL by 82% (September 2020 - May 2021) compared to the same 9 months prior to the pandemic (Figure 1A, red line). This finding is similar to an estimated 79% reduction in non-resident visitor volume to NL for 2020 compared to 2019 (Government of

Newfoundland and Labrador, 2020). The reduction in travel to NL may have been higher than for other regions, since across all countries air travel is estimated to have declined by less (63%) for May 2020 (during the pandemic) as compared to May 2019 (before the pandemic, Russell et al 2021).

We found that during the pandemic there was a 10% increase in arrivals from Alberta, and 10% decrease in arrivals from Québec (Figure 2). Evidence for this result can be seen in table B6, where the percentages before the pandemic (January 2019 - March 2020) are calculated from the IATA data, and the percentages during the pandemic (September 2020 - May 2021) are calculated from the TDF data. This shift may be explained by the high percentage of rotational workers that work in Alberta (57%) as compared to Québec (2%; table B6), while the travel volume of regular travelers from Québec before the pandemic is relatively high (11-26%, third highest behind Ontario and Nova Scotia, table B6). Rotational workers likely continued working during the pandemic, while regular travelers may have delayed or cancelled trips. Importation models used during public health emergencies often consider the product of infection prevalence at the travelers origin multiplied by the travel volume from that origin (i.e., equation 1 in Nakamura and Managi 2020). An implication of our findings are that the travel volume data used for these calculations needs to correspond to the period of the public health emergency, because the fraction of non-essential travel that can be delayed or cancelled is likely not constant across origin-destination pairs.

Our results suggest two reasons why it is necessary to formulate importation models at small spatial scales. First, to predict daily travel-related cases arriving in NL from Canadian origins, the model that considers each of the Canadian provinces and the territories individually outperformed a similar model that combined travel volume and infection prevalence for all of Canada, even when considering that fewer parameters were fitted (ΔAICc = 101.4, table 1). Second, none of our models predicted the daily number of travel-related cases from international origins adequately ($R^2 < 0.06$ for all models, table 1), which may be because we did not individually consider each country because serology data to estimate the coefficient of infection under-reporting was unavailable for most countries.

Our results also suggest that it is necessary to test travelers and publicly report travel-related cases so that importation models to support public health decisions can be developed during public health emergencies. While it is possible to predict importations based on a description of the epidemiological processes and travel volumes alone (Hincapie et al, 2022; Linka et al, 2020; Nakamura and Managi, 2020; Russell et al, 2021), our epidemiological model when validated explained only 15.6% of the variance in daily travel-related cases arriving in NL from Canada. We found that a substantial amount of predictive value is added when the data reporting travel-related cases is available to be considered in the modelling (table 1). Some models have implicitly assumed that when infection first establishes in a new region most cases will be travel-related, i.e., Wells et al (2020) and Chinazzi et al (2020). The analysis of Hossain et al (2020) (see figure 4 in Hossain et al 2020) suggests this approach may be reasonable, however, Hossain et al (2020) fit a reporting delay parameter, which makes the validity of this approach less clear, as the performance of a model where the reporting delay parameter is estimated independently is unknown.

There are number of reasons why the predictions of importation models may not hold and should be validated. Data quality may not be sufficient to make accurate predictions. Many studies consider only air travel volumes (Chinazzi et al, 2020; Hincapie et al, 2022; Nakamura and Managi, 2020; Russell et al, 2021; Wells et al, 2020), although travelers are likely to arrive via other travel modes and this proportion may change seasonally. No one travel volume data source reports the epidemiologically-relevant travel volume. Travel documents completed at international borders omit travelers that originate from within the country, and not all travel between countries requires such documents be completed (i.e., travel between countries in the European Union). Provinces may conduct surveys to understand tourist preferences, but such surveys (i.e., Government of Newfoundland and Labrador 2020-2021) usually focus only on non-resident travel, while returning residents and workers are a potential source of imported infection. It may be difficult to accurately and consistently estimate infection prevalence reported across regions due to differences in accessibility of testing, available resources for testing, willingness of different populations to get tested, and lack of seroprevalence data.

Both travel volume and infection prevalence data may be only available for large spatial scales: even the provincial-level, as considered in this study, maybe too large as it is known that infection prevalence can vary on the neighborhood scale (Xia et al, 2022), and such averaging may impact the predictions of importation models. Further, it is assumed that travelers are drawn randomly from the population at the origin, whereas in practice travelers may be of a higher income, which is associated with lower infection prevalence (Wang et al, 2022).

Overall, our results highlight the importance of testing travelers and reporting travel-related cases alongside traveler characteristics, such as travel origin and reason for travel. Estimating model parameters from data describing travel-related cases improves model predictions much more substantially than formulating models with more epidemiological realism. Importation models require real-time travel volume data and quality data describing infection prevalence at traveler's origins, and both need to be reported at small spatial scales. Such improvements in data quality and availability are needed for importation models to support decision-making during public health emergencies.

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Declarations

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- **Competing interests.** AH was a member of the Newfoundland and Labrador Predictive Analytics modelling team and previously received funding from the Newfoundland and Labrador Centre for Health Information.
- **Ethics approval.** Newfoundland and Labrador Health Research Ethics Board reference number 2021.013
- **Availability of data and materials.** The Newfoundland and Labrador Centre for Health Information (NLCHI) is the data custodian for the Travel Declaration Form data and Newfoundland and Labrador COVID-19 cases.
- **Code availability.** The code used for analysis is publicly available.
- **Authors' contributions.** All authors conceptualized the study. ZM cleaned the data, completed the analysis, and made all the figures. ZM and AH interpreted the results and wrote the manuscript. All authors edited the manuscript.

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Appendix A Model overview

The epidemiological model that we develop to compare with the validation data considers: (i) travel volume to NL; (ii) infection prevalence at a traveler's origin; (iii) SARS-CoV-2 epidemiology, and (iv) the travel restrictions and SARS-CoV-2 testing regulations that occurred in NL from September 2020 to June 2021 (Figure A1).

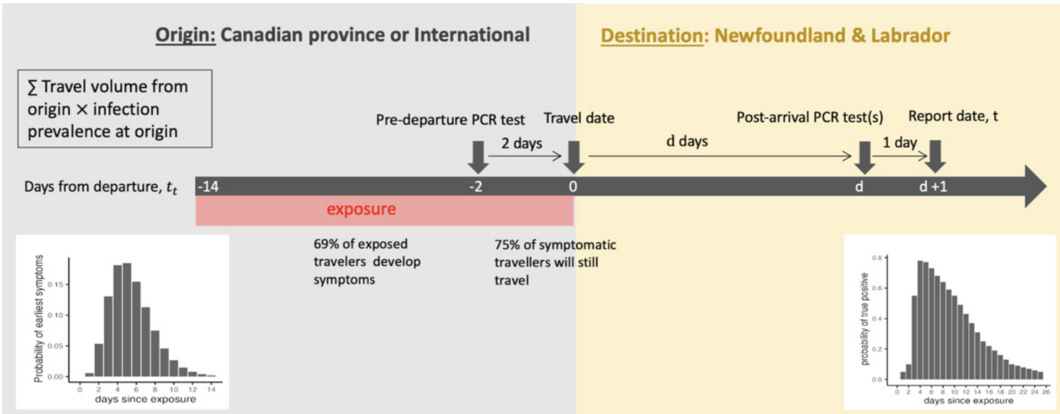

Fig. A1 A visual overview of the epidemiological model. Travel occurs at $t_t = 0$. The number of days between the date of travel and the date of required testing is $d = \{j_1, j_2, j_3, \bar{a} + t_r, t_r\}$ days after arrival. A pre-arrival test was required for travelers departing from international origins from January 7, 2021. It is assumed that infected travelers were exposed between 0 and 13 days before departure. Probability mass functions describe the timing of first symptoms, and the probability of a true positive Polymerase Chain Reaction (PCR) test as these quantities depend on the number of days since exposure.

Table A1 Parameter values

Symbol	Definition	Value	Reference
N_i	population size for the travel origin, i, in 2021. i is each Canadian province except NL, and the Canadian territories and international origins.	Table. C7	Statistics Canada (2021); The United States government (2021)
u_i	correction for infection under-reporting at origin i	Table C7	App. C
t_d	delay between exposure and reporting at travellers origin	11 days	Assumed
$\lambda(a)$	Probability of first developing symptoms given exposure a days ago	equation C10	Lauer et al (2020)
$t_{sens}(a)$	probability of a true positive given exposure a days ago	App. C	Hellewell et al (2021); Hurford et al (2023)
ψ	fraction of travelers who travel despite having symptoms	0.75	Smith et al (2020)
ρ	fraction of infections that are symptomatic	0.69	Godin et al (2021)
t_t	date of arrival in NL	all dates	
P^S	probability that symptomatic regular travellers get tested in NL	0.8	Assumed
P_i^A	proportion of all travelers that were infected on a flight, and were tested after exposure notifications were issued (Tab. D9)	0.01	App. C
$\bar{a}$	the average number of days after arrival when symptoms first occur	1 day	See equation D18. The exact value is 1.49 days.
t_e	the number of days after arrival when an exposure notifications was issued	3 days	Assumed. Ranged between 2 and 7 days.
t_r	delay between requesting a post-arrival test and the test occurring (for travellers without scheduled tests)	3 days	Assumed
t_{rep}	delay between testing and reporting in NL	1 day	Assumed

Appendix B Estimating travel volume

B.1 Overview of method to estimate travel volume

We estimated the travel volume arriving in NL by considering three data sources: International Air Transit Authority (IATA), Travel Declaration Forms (TDF), and Frontier Counts (FC), each with limitations and each reported for different time periods (table B2). This section describes how to estimate the total travel volume considering all modes, travelers and crew, and how the limitations of each data source were corrected.

Table B2 Limitations of data sources. All 3 data sources International Air Transport Authority (IATA, $s = 1$), Travel Declaration Forms (TDF, $s = 2$), and Frontier Counts (FC, $s = 3$) report an origin (either Canada or international), but report travel volumes that exclude some travelers that might spread infections to NL residents. When exclusions apply to a particular data source and origin (Canada or international) the value of the indicator variable is 1 (and 0 otherwise). The magnitude of the correction for the exclusion is given in table B3 (see also equation B1). The travel origin in TCAR reports ($s = 4$) was not reported, but the information in these reports was used to estimate the volume of travelers excluded from the reported travel volumes for the other data sources.

s	Data Source	Time frame, t	Pandemic	Travel Mode	$\mathbb{1}_{\text{MODES}} =$	Origin, $i \in$	Traveler exclusions	$\mathbb{1}_{\text{EXCL}} =$	Documents
1	International Air Transport Authority (IATA)	Jan 2019 - March 2020 (monthly)	before	air	1	{CA, INT}	Crew	1 if i = CA 0 if i = INT	App. B.2
2	Travel Declaration Forms (TDF)	Sep 2020 - May 2021 (daily)	during	air, sea, land	0	{CA, INT}	NL residents, crew, and other exempt travelers	1	App. B.2
3	Frontier Counts (FC)	Jan 2019 - May 2021 (monthly)	before and during	air, sea, land	0	{INT}	None	0	App. B.2
4	Department of Tourism, Culture, Arts, and Recreation (TCAR)	Jan 2019 - Dec 2021 (monthly)	before and during	air, sea, land	0	Unknown	NL residents	0	App. B.3

We estimate the total travel volume considering all travel modes, travelers and crew from the origin i at time t by introducing indicator variables that correct for exclusions in the data sources,

$$V_{i,s}(t) = (1 + \alpha_{i,s}(t)\mathbb{1}_{\text{MODES}})Z_{i,s}(t) + \lambda_{i,s}(t)\mathbb{1}_{\text{EXCL}}, \tag{B1}$$

where $Z_{i,s}(t)$ is the number of travelers arriving from origin i per day ($s = 2$), or per month ($s = 1, 3$) reported from a data source, s. Possible origins are international ($i = \text{INT}$) or Canada ($i = \text{CA}$), but in subsequent calculations below we will further partition $i = \text{CA}$ into each Canadian province and the territories (where all three Canadian territories are combined).

The indicator variable $\mathbb{1}_{\text{MODES}}$ applies to data that does not report arrivals by all modes, and applies to the IATA data ($s = 1$) because this travel volume reports only arrivals by air. The correction factor, $\alpha_{i,s}(t)$, multiplies the reported travel volume by air. The indicator variable $\mathbb{1}_{\text{EXCL}}$ applies when some individuals are excluded from the reported travel volume, and the correction is additive. This correction applies to the IATA data, $\lambda_{i,1}(t)$, for crew members that are not reported, and to the TDF data, $\lambda_{i,2}(t)$, because arriving crew members on flights, ships, commercial freighters, NL residents, and other exempt travelers are not reported in this data.

The travel volume, $V_{i,s}(t)$, corrected for reporting omissions can be calculated for all data sources s, however, in practice the calculated values do not have a lot of overlap because the IATA data only corresponds to pre-pandemic time periods, the TDF data only corresponds to during the pandemic, and the FC data only reports travelers of international origin.

In equation B1, i refers to Canadian or international origin of travel, but both the IATA and TDF data report the Canadian province or territory of origin. Therefore, we estimate travel volume from different Canadian provinces, and the territories as,

$$v_{i,s}(t) = V_{\text{CA},s}(t)h_i^{tot}(t), \tag{B2}$$

Table B3 Parameter values used to estimate the total travel volume arriving in Newfoundland and Labrador from Canadian and international origins.

Symbol	Description	Value
$Z_{i,s}(t)$	Number of travellers arriving from origin i as reported by data source s	see Figure 1A. For the FC data, $s = 3$, we just have $i = INT$.
$\alpha_{i,s}(t)$	Correction factor to estimate travellers by modes other than air	Values vary for different time periods with complete details in Table B6. $\alpha_{CA,1}(t)$ values are between 0.14 and 0.37, which means that travel volumes increase by 14-37% when the exclusions are considered. $\alpha_{INT,1}(t)$ was determined based on the FC data ($s = 3$) as this data reported arrivals for international origins for all modes.
$\lambda_{i,s}(t)$	For the IATA data ($s = 1$) excluded travellers are domestic crew members. For the TDF data ($s = 2$) exempt travelers are crew, NL residents, and other exempt travellers	Values vary monthly with complete details in Table B6. $\lambda_{\text{CA},1}(t)$ is between 2,107 and 24,952, $\lambda_{\text{CA},2}(t)$ is between 5,863 and 15,048, and $\lambda_{\text{INT},2}(t)$ is between 1,916 and 5,620 travellers excluded each month.
$h_i^{tot}(t)$	Fraction of travellers from each Canadian province and territory	Values vary monthly with complete details in Table B6.
h_i^{rw}	Fraction of rotational workers from each Canadian province or territory	Assumed not to vary over time with values reported in Table B6.

where $h_i^{tot}(t)$ is the fraction of all Canadian travelers originating from each of the different non-NL provinces or the territories $i \in \{$BC, AB, SK, MB, ON, QC, NB, NS, PE, TR$\}$ on a given date t, where Yukon, Northwest territories, and Nunavut are combined and denoted as TR, and $s = 1$ corresponds to the IATA data when we are considering before the pandemic, and $s = 2$ corresponds to the TDF data when we are considering during the pandemic.

During the public health emergency in NL, some different travel restrictions were applied to rotational workers. Rotational workers are NL residents that work in other provinces. The number of rotational workers entering NL is difficult to estimate, but Martignoni et al (2021) estimates that 6,000 NL residents are rotational workers. If we assume a rotational worker has a set schedule of two weeks of work and home (alternating), then approximately 200 rotational workers will enter NL each day. The fraction of rotational workers that work in any given province or the Canadian territories, $i \in \{$BC, AB, SK, MB, ON, QC, NB, NS, PE, TR$\}$, is h_i^{rw}, which is estimated from Hewitt et al (2018) (see table B6). Therefore, the number of rotational workers arriving in NL during the pandemic from each of the different provinces and territories is,

$$v_i^{rw}(t) = 200 h_i^{rw}. \tag{B3}$$

The number of regular travelers (defined as all individuals that are not rotational workers) arriving from a Canadian origin, i, during the pandemic is,

$$v_i^{r}(t) = v_{\text{CA},2}(t) - v_i^{rw}, \tag{B4}$$

where the travel volume is estimated from the TDF data ($s = 2$) because this data source corresponds to during the pandemic. The quantity $v_i^{rw}(t)$ does not change with time, but $v_i^r(t)$ does, so the dependence on time is written so that the compacted notation $v_i^k(t)$ can be used. We define

$$v_i^{r}(t) = v_{\text{INT},2}(t), \tag{B5}$$

as the volume of regular travelers arriving from international origins during the pandemic for this same reason, such that $v_i^k(t)$ is the volume of travelers arriving during the pandemic at time, t, that are rotational workers ($k = rw$, $i = \text{CA}$), regular travelers arriving from a Canadian origin ($k = r$, $i = \text{CA}$), or from an international origin ($k = r$, $i = \text{INT}$).

B.2 Data sources - travel volume

B.2.1 Pre-pandemic

IATA data reported the number of passengers travelling in all classes for flights to and from Newfoundland and Labrador from January 2019 through March 2020 (International Air Transport Association, 2020). We focus on the origin and destination that were reported for each flight (not layovers). We classify the data into three categories: inbound, outbound, and within the province. In this work, we use inbound air travel volume.

B.2.2 During the pandemic

In response to the COVID-19 pandemic in Newfoundland and Labrador, several travel measures were implemented at the federal or provincial level. On March 20, 2020, 14-day self-isolation was ordered for all (national and international) individuals entering Newfoundland and Labrador from outside the province (Exemption Order, 2020). This order included some exemptions, e.g. workers in transportation, essential workers, rotational workers, etc (Exemption Order 2, 2020). At this time, foreign nationals entering Canada by air was prohibited for all countries except the United States (Trudeau, 2020), and with air crews, travelers arriving in Canada in transit to a third country, Canadian permanent residents, diplomats, or immediate family members of Canadian citizens exempt. Further provincial travel restrictions were implemented on April 23, 2020 (Amendment No. 6, 2020) requiring that all individuals arriving in Newfoundland and Labrador from outside the province must complete a declaration form (TDF) and have a self-isolation plan to submit to a government representative upon entry. Also, all individuals arriving in the province by motor vehicle from the province of Québec must immediately stop at their point of entry indicated by a representative of the Government of Newfoundland and Labrador, to submit their declaration form and their self-isolation plan (Amendment No. 8, 2020).

Effective May 4, 2020, all individuals were prohibited from entering Newfoundland and Labrador except residents of Newfoundland and Labrador, asymptomatic workers, and individuals who received a travel exemption (Amendment No.11, 2020; Travel Exemption Order, 2020). There were limited exempted individuals who were not required to complete the declaration form and submit the self-isolation plan. These were travelers who stayed in the province less than 24 hours, arrive daily or several times a day via the Labrador-Québec border, enter the province via the Labrador-Québec border for school reasons, or arrive weekly or several times a week in the province (Declaration Exemption Order, 2020; Self-Isolation Exemption Order, 2020). Submitting a declaration form order at the Labrador-Québec border relaxed further on June 25, 2020, especially for the residents of Labrador City, Wabush, Fermont, the Labrador Straits area, Blanc Sablon, and greater Québec Lower North Shore area (Labrador-Quebec Border Amendments, 2020). Completing a declaration form was required even when the Atlantic Bubble was enacted (Atlantic Travel Amendments, 2020). All these travel orders were in place until the first phase of reopening. Effective on July 1, 2021, an approved reason to travel to the province, and completion of a TDF, was no longer required (Re-Opening - Travel, 2021). We use the declaration form information compiled by the Newfoundland and Labrador Centre for Health Information to estimate arrival volume in the province during the pandemic.

Table B4 Federal and provincial travel measures in Newfoundland and Labrador from September 2020 to May 2021 (Canadian Institute for Health Information, 2022; Government of Newfoundland Labrador, 2020-2022).

Line	Dates	Measure	Level
1	2020-03-13	Cruise ship season postponed	Fed
2	2020-05-04	Travel restrictions on non-resident entry announced	Prov
3	2020-06-09	Travel restrictions on foreign nationals with immediate family in Canada relaxed	Fed
4	2020-07-03	Travel bubble with P.E.I., N.B. and N.S. announced allowing entrance without requirement to self-isolate	Prov
5	2020-08-31	Travel restrictions eased for non-Atlantic Canada residents who own a second home or cabin in Newfoundland and Labrador	Prov
6	2020-10-20	Travel restrictions for international students attending institutions with a COVID-19 readiness plan eased	Fed
7	2020-11-25	Travel into the province from the Atlantic bubble restricted to essential travel only	Prov
8	2021-02-01	Announced that all international passenger flights must land either at the Vancouver, Calgary, Toronto or Montréal airports	Fed
9	2021-03-27	Limited passengers on provincial ferries to essential travelers only	Prov

B.2.3 All time

The Frontier Counts (FC) provide counts of entries into Canada by international travelers at Canadian ports of entry. The target population is defined as all international travelers that were categorized as: Canadian residents returning to Canada, United States of America residents entering Canada, residents of countries other than the

United States of America entering Canada and 'other' travelers which consist of foreign and resident crew members, diplomats, military personnel, immigrants and former residents (Statistics Canada, 2020-2021). For this study, we focus on Newfoundland and Labrador ports of entry. Therefore, our variable (travel volume) is all entries into the province from international origins.

Data reported by Frontier Counts are extracted from different data sources provided by the Canada Border Services Agency (CBSA), i.e., Primary Inspection Kiosks (electronic systems at major airports), E311 Declaration Cards (forms completed at Canadian international airports without electronic system), and Telephone Reporting Centre (TRC)-CANPASS (an electronic system for private plane or private boat or who report a land crossing by phone) (Statistics Canada, 2020-2021).

B.3 Estimating travel volumes not reported in the data sources

B.3.1 Non-air travel volume from Canadian origins

Reports from the Department of Tourism, Culture, Industry, and Innovation, Newfoundland and Labrador government from 2011 to 2018 indicate that air travel is the main mode of arrival for visitors to NL regardless of the season. The mean percentage of non-NL resident visitors arriving by air, auto, and cruise ships was 76%, 18%, and 6% respectively over three years 2016 to 2018 (Government of Newfoundland Labrador, 2017, 2018a).

From May to October 2016, 73% of non-NL residents arriving from Canadian origins to Newfoundland and Labrador were by air (Government of Newfoundland Labrador, 2016), for arrivals from international origins this value was 85% (Government of Newfoundland Labrador, 2018), and with the remaining non-NL resident arrivals occurring by auto/ferry. Regardless of origin, the fraction of non-NL resident visitors who are using auto/ferry in spring (27%) was more than in fall (19%) (Government of Newfoundland Labrador, 2017).

Using all the TCAR reports from the Government of Newfoundland and Labrador (2020-2021), we estimated a correction factor, $\alpha_{CA,1}(t)$, to calculate the total travelers (air and auto/ferry) originating from Canada from the air arrival data (IATA). The estimated value multiplies the travel volume by air from Canadian origins and is 1.24 for September, October, November, and March, 1.14 for winter months (December, January, and February) and 1.37 for warmer months in spring and summer (April to August). For international arrivals, this correction for arrivals by auto/ferry is not necessary owing to the Frontier Counts data, which reports arrivals by all travel modes.

B.3.2 Crew members and exempt travelers

Monthly crew member travel volume from international origins was obtained from the Frontier Counts data source, $s = 3$, both before and during the pandemic. The number of travelers per month that were crew members from Canadian origins is assumed to be 2.5 times the volume of crew members from international origins.

The Travel Declaration From (TDF) data reported arriving travel volume each day from Canadian or international origins during the pandemic. TDF data does not consider travelers who were exempt from completing the form (Appendix B.2). We were able to estimate the correction for excluded travelers for each month, and assumed an equal number of excluded travelers arrived each day during that month.

To estimate the number of exempt travelers from international origins, we compared the two data sources $s = 2$ and $s = 3$ (see table B2). Since $Z_{\text{INT},3}$ included all international arrivals, the difference between this data source and $Z_{INT,2}$ is the number of international exempt travelers per month, $\lambda_{\text{INT},2}(t)$.

Travelers from Canada exempt from filling out a TDF were interprovincial workers, NL residents, domestic crew members, exempt travelers via the Labrador-Québec border (see table B.2). The correction applied to the TDF data source, $\lambda_{\text{CA},2}(t)$, accounts for the exclusion of both domestic crew members and other exempt travelers. To estimate the portion of other exempt travelers (not crew) as arriving travelers, we assumed that the number of total exempt arrivals (residents and non-residents) was 2.4 times the number of exempt non-NL resident arrivals (see Aleman et al 2021 for a justification of this assumption), where the number of exempt non-NL resident arrivals from domestic origins is assumed to equal the number of exempt non-NL residents arriving from international origins per month.

This value of 2.4 may be an over-estimate, but this over-estimate compensates for underestimation for other reasons such as challenges in submitting the TDF for travelers arriving by land.

B.3.3 Percentage of travelers arriving from different origins

The TDF data (during the pandemic) was used to estimate the monthly percentage of travelers originating from each country for the international travel volume arriving to Newfoundland and Labrador during the pandemic (table B5). These values show that the United States comprises a high percentage of arrivals from international origins, such that our assumption that infection prevalence for international arrivals is equal to infection prevalence in the United States might be reasonable.

Table B5: Percentage of travel volume from international origins during the COVID-19 pandemic, September 2020 to May 2021

Origins	2020-09	2020-10	2020-11	2020-12	2021-01	2021-02	2021-03	2021-04	2021-05
Argentina	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.153	0.000
Mauritius	0.000	0.000	0.000	0.000	0.305	0.377	0.000	0.000	0.118
Mexico	0.000	7.692	0.000	2.336	1.829	2.264	0.615	1.227	1.294
Montenegro	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.153	0.000
Morocco	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.235
Moszenbeque	0.000	0.000	0.000	0.000	0.000	0.000	0.205	0.000	0.000
Mozambique	0.000	0.000	0.000	0.000	0.305	0.000	0.000	0.000	0.118
Myanmar	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.118
Namibia	0.000	0.000	0.000	0.234	0.000	0.000	0.205	0.000	0.000
Nepal	0.000	0.000	0.000	0.000	0.000	0.755	0.000	0.000	0.235
Netherlands	0.000	0.000	0.990	0.935	0.610	0.000	1.230	1.687	1.176
New.Zealand	0.000	1.923	0.000	0.000	0.610	0.000	0.000	0.000	0.000
Nigeria	0.000	1.923	0.000	1.402	1.524	3.019	1.434	1.994	1.529
Norway	0.000	1.923	7.921	2.804	3.659	2.264	1.639	2.301	1.412
Oman	0.000	0.000	0.000	0.467	0.000	0.000	0.000	0.153	0.118
Pakistan	0.000	0.000	0.000	0.467	0.610	1.509	1.434	0.307	0.000
Panama	0.000	0.000	0.990	0.000	0.000	0.000	0.000	0.153	0.000
Papua.New.Guinea	0.000	1.923	0.000	0.000	0.000	0.755	0.000	0.000	0.000
Australia	0.000	0.000	0.000	0.701	0.305	0.377	0.410	0.767	0.588
Peru	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.353
Philippines	0.000	1.923	0.000	4.439	0.915	1.887	1.434	4.755	2.000
Poland	0.000	0.000	0.000	0.234	0.305	0.000	1.639	0.307	2.588
Portugal	0.000	0.000	0.000	0.234	0.915	0.000	0.410	0.614	0.235
Qatar	0.000	0.000	0.000	1.869	0.305	3.019	0.205	1.074	1.412
Romania	0.000	0.000	0.000	0.234	0.305	0.000	0.205	0.153	0.235
Russia	0.000	0.000	0.000	0.234	0.000	0.377	0.410	0.460	0.824
Rwanda	0.000	0.000	0.000	0.000	0.000	0.377	0.205	0.307	0.000
Saudi.Arabia	0.000	1.923	0.000	1.402	1.220	1.509	0.205	0.614	0.824
Austria	0.000	0.000	0.000	0.234	0.610	0.000	0.000	0.000	0.118
Scotland	0.000	3.846	0.990	0.935	0.610	1.132	2.254	3.067	0.000
Serbia	0.000	0.000	0.000	0.000	0.000	0.000	0.205	0.153	0.118
Singapore	0.000	0.000	0.000	0.234	0.000	0.755	0.000	0.153	0.471
Sint.Maarten	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.153	0.000
Slovenia	0.000	0.000	0.000	0.000	0.610	0.000	0.000	0.000	0.000
South.Africa	0.000	0.000	0.000	0.000	0.000	1.132	1.025	0.460	0.235
South.Korea	0.000	0.000	0.000	0.000	0.000	0.377	0.000	0.153	0.000
Azerbaijan	0.000	0.000	0.000	0.234	0.000	0.000	0.410	0.000	0.353
Spain	0.000	3.846	0.990	3.738	3.354	2.642	0.615	1.380	4.235
Srilanka	0.000	0.000	0.990	0.234	0.610	1.509	0.615	0.153	0.471
St..Kitts.and.Nevis	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.153	0.000
Suriname	0.000	0.000	0.000	0.935	0.305	0.755	1.434	14.877	0.000
Sweden	0.000	1.923	0.000	0.234	0.000	0.000	0.000	0.460	0.235
Switzerland	0.000	0.000	0.000	0.234	0.305	0.000	0.615	0.000	0.235
Taiwan	0.000	1.923	0.000	0.234	0.000	0.377	0.000	0.000	0.235
Tanzania	0.000	0.000	0.000	0.000	0.305	1.132	0.000	0.000	0.353
Thailand	0.000	0.000	0.000	0.000	0.305	0.000	0.000	0.153	8.235
Trinidad.and.Tobago	0.000	0.000	0.990	0.935	2.439	2.642	1.230	2.147	1.647
Tunisia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.118
Turkey	0.000	0.000	0.000	0.467	1.220	1.132	0.205	0.920	0.000
UAE	0.000	1.923	0.000	0.234	0.915	0.000	0.410	1.227	0.588
UK	16.667	13.462	16.832	10.047	9.451	7.925	3.074	2.607	11.059
Bangladesh	0.000	0.000	0.000	1.636	2.439	6.038	3.074	1.227	3.529
Ukraine	0.000	0.000	0.000	0.000	0.610	0.000	0.000	0.153	0.353
USA	50.000	44.231	48.515	36.682	32.012	24.151	39.139	30.675	32.706
Uzbekistan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.118
Vietnam	0.000	1.923	0.000	0.000	0.610	0.000	0.000	0.000	0.118
Wales	0.000	0.000	0.000	0.000	0.000	0.000	0.410	0.000	0.000
Zambia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.153	0.235
Zimbabwe	0.000	0.000	0.000	0.000	0.305	0.377	0.205	0.307	0.235
Barbados	0.000	0.000	0.990	0.000	0.000	0.377	0.000	0.307	0.118
Belgium	0.000	0.000	0.000	0.000	0.000	0.000	0.205	0.000	0.000
Belize	0.000	0.000	0.000	0.467	0.000	0.000	0.205	0.153	0.118
Benin	0.000	0.000	0.000	0.000	0.305	0.000	0.000	0.000	0.000
Bermuda	0.000	0.000	0.000	0.234	0.000	0.377	0.000	0.000	0.000
Bolivia	0.000	0.000	0.000	0.000	0.000	0.377	0.000	0.000	0.000
Bosnia.and.Herzegovina	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.153	0.000
Botswana	0.000	0.000	0.000	0.000	0.000	0.377	0.000	0.000	0.000
Brazil	8.333	0.000	0.990	1.168	2.744	1.509	1.434	1.227	0.588
Brunei	0.000	0.000	0.000	0.234	0.000	0.377	0.205	0.000	0.118
Bulgaria	0.000	0.000	0.000	0.000	0.000	0.000	0.410	0.153	0.235
Cameroon	0.000	0.000	0.000	0.000	0.000	0.377	0.410	0.000	0.235
Cape.Verde	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.307	0.000
Caribbean	0.000	0.000	0.000	1.402	0.610	0.377	0.205	0.460	1.294
Chad	0.000	0.000	0.000	0.000	0.305	0.000	0.000	0.000	0.000
Chile	0.000	0.000	0.000	0.000	0.610	0.377	0.000	0.000	0.000
China	8.333	0.000	0.000	0.935	0.610	0.755	0.615	0.920	1.294
Colombia	0.000	0.000	0.000	0.000	0.610	0.000	0.000	0.153	0.118
Congo..DRC.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.353
Costa.Rica	0.000	0.000	0.000	0.234	0.305	0.000	0.000	0.000	0.235
Croatia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.227	0.353
Africa	0.000	0.000	0.000	0.234	0.305	0.755	0.205	0.153	0.000
Cuba	0.000	0.000	0.000	0.234	0.305	0.000	0.000	0.000	0.000

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Table B5 – continued from previous page

International Origins	2020-09	2020-10	2020-11	2020-12	2021-01	2021-02	2021-03	2021-04	2021-05
Czech.Republic	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.118
Denmark	0.000	0.000	0.990	0.467	0.610	1.509	0.410	0.307	1.059
Dominican.Republic	0.000	0.000	0.000	0.467	0.305	0.000	0.000	0.000	0.235
Ecuador	0.000	0.000	0.000	0.000	0.000	0.000	0.205	0.000	0.235
Egypt	8.333	0.000	1.980	0.234	1.220	0.755	0.615	0.920	0.824
El.Salvador	0.000	0.000	0.000	0.234	0.000	0.000	0.000	0.000	0.000
Albania	0.000	0.000	0.990	0.000	0.000	0.000	0.205	0.000	0.000
Ethiopia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.614	0.000
Faroe.Islands	0.000	0.000	0.000	0.000	0.000	0.377	0.205	0.000	0.471
Finland	0.000	0.000	0.000	0.234	0.000	0.377	0.205	0.000	0.118
France	0.000	1.923	1.980	1.402	2.744	0.755	13.320	1.227	0.588
Gabon	0.000	0.000	0.000	0.000	0.000	0.000	0.205	0.000	0.000
Germany	0.000	0.000	2.970	1.168	0.610	1.132	1.639	1.074	0.471
Ghana	0.000	0.000	0.000	0.234	0.610	2.264	0.410	0.614	0.235
Greece	0.000	0.000	0.990	0.234	0.000	0.000	0.205	0.153	0.118
Guatemala	0.000	0.000	0.000	0.000	0.000	0.000	0.205	0.000	0.118
Guyana	8.333	0.000	0.000	3.037	3.963	1.132	1.844	1.687	1.294
Holland	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.307	0.000
Honduras	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.153	0.000
Hong.Kong	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.153	0.118
Hungary	0.000	0.000	0.000	0.234	0.000	0.000	0.000	0.153	0.118
Iceland	0.000	0.000	2.970	0.467	0.305	0.755	0.000	0.614	0.118
India	0.000	0.000	0.990	2.804	1.524	4.906	3.484	3.221	0.471
Indonesia	0.000	0.000	0.000	0.467	0.000	0.000	0.000	0.153	0.118
Amsterdam	0.000	0.000	0.000	0.234	0.000	0.000	0.000	0.000	0.000
Iran	0.000	0.000	0.000	0.935	3.963	3.019	0.205	1.074	1.176
Iraq	0.000	0.000	0.000	0.000	0.305	0.000	0.000	0.000	0.000
Ireland	0.000	0.000	1.980	2.103	1.829	1.132	0.820	0.920	1.294
Israel	0.000	0.000	0.000	0.467	0.000	0.000	0.000	0.153	0.000
Italy	0.000	5.769	0.990	0.000	0.305	1.132	0.615	0.000	0.235
Jamaica	0.000	0.000	0.990	0.467	0.305	0.000	1.434	0.614	0.588
Japan	0.000	0.000	0.000	0.000	0.305	0.000	0.000	0.614	0.706
Jordan	0.000	0.000	0.000	0.467	0.610	0.755	0.615	0.000	0.471
Kazakhstan	0.000	0.000	0.000	0.467	0.000	1.132	0.000	0.460	0.118
Kenya	0.000	0.000	0.000	0.467	0.305	0.377	0.410	0.153	0.235
Angola	0.000	0.000	0.990	1.402	0.610	0.755	1.434	0.920	0.353
Kosovo	0.000	0.000	0.000	0.000	0.000	0.377	0.000	0.000	0.000
Kuwait	0.000	0.000	0.000	0.000	1.220	0.000	0.000	0.153	0.235
Kyrgyzstan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.118
Latin.America	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.235
Latvia	0.000	0.000	0.000	0.701	0.000	0.000	0.205	0.000	0.000
Lebanon	0.000	0.000	0.000	0.000	0.305	0.000	0.205	0.153	0.118
Libya	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.118
Lithuania	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.118
Antigua...Barbuda	0.000	0.000	0.000	0.000	0.305	0.000	0.000	0.000	0.000
Luxembourg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.118
Malaga	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.153	0.000
Malawi	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.153	0.000
Malaysia	0.000	0.000	0.000	0.234	0.000	0.755	0.000	0.000	0.471
Martinique	0.000	0.000	0.000	0.000	0.000	0.000	0.205	0.000	0.000
Mauritania	0.000	0.000	0.000	0.000	0.305	0.000	0.000	0.000	0.000

The percentage of travel volume for each province or the territories from the IATA and TDF data was used to estimate the percentage of regular travelers arriving from each of these origins (table B6) before and during the pandemic.

The percentage of NL interprovincial employees that work in each Canadian province or the territories is reported by Hewitt et al 2018. In this report, the largest number of interprovincial employees work in Alberta (57%), followed by Ontario (15%) and Nova Scotia (8%). Manitoba had the lowest percentage of interprovincial employees from NL. These values are used to estimate the within-Canada origin of rotational workers (table B6)

Table B6 Values for the parameters in table B3. $h_i^{tot}(t)$ (per month) is the fraction of Canadian travel volume that originates from each individual province or the territories. $\alpha_{\mathrm{CA},1}(t)$ is the correction factor to estimate the number of travellers arriving from Canada by modes other than air before the pandemic. $\lambda_{\mathrm{CA},1}(t)$ is the number of excluded travellers for data source $s = 1$ per month (pre-pandemic) whereas $\lambda_{\mathrm{CA},2}(t)$ and $\lambda_{\mathrm{INT},2}(t)$ are the monthly number of Canadian and international excluded travelers from data source $s = 2$ (during the pandemic). h_i^{rw} is the fraction of rotational workers from each Canadian province and territory.

$h_i^{tot}(\%)$											$\alpha_{\mathrm{CA},1}(t)$	$\lambda_{\mathrm{CA},1}(t)$	$\lambda_{\mathrm{CA},2}(t)$	$\lambda_{\mathrm{INT},2}(t)$
date	ON	QC	MB	NB	AB	NS	BC	SK	PEI	TR	CA	CA	CA	INT
2019-01	31.69	24.35	0.58	3.5	8.82	27.15	2.16	0.52	1.03	0.2	0.14	2920		
2019-02	32.05	25.84	0.68	3.79	7.52	26.88	2	0.44	0.61	0.21	0.14	2417		
2019-03	33.07	24.07	0.75	3.73	6.99	27.97	2.29	0.29	0.49	0.35	0.24	3642		
2019-04	33.8	22.96	0.72	3.97	7.72	27.03	2.09	0.6	0.75	0.36	0.37	3150		
2019-05	37.07	17.07	1.07	3.7	7.88	28.66	2.64	0.87	0.69	0.34	0.37	4750		
2019-06	42.03	13.73	1.49	3.23	9.74	23.9	4.1	0.58	0.68	0.53	0.37	5702		
2019-07	45.19	11.03	1.37	2.7	13.31	20.21	4.3	0.94	0.54	0.41	0.37	14075		
2019-08	44.14	11.81	1.17	2.83	10.7	22.29	4.67	1.22	0.73	0.45	0.37	6650		
2019-09	38.38	16.25	1.5	3.55	8.26	26.09	3.76	0.92	0.93	0.36	0.24	24952		
2019-10	33.86	19.34	1.1	3.33	9.14	28.6	2.9	0.47	0.73	0.52	0.24	9395		
2019-11	33.32	18.8	0.55	3.99	8.1	30.33	2.84	0.52	1.1	0.44	0.24	2842		
2019-12	34.95	14.93	0.9	4.05	10.99	27.68	4.4	0.59	0.8	0.7	0.14	2445		
2020-01	35.01	16.69	0.78	4.39	9.57	28.1	3.87	0.62	0.7	0.27	0.14	2107		
2020-02	33.33	19.82	0.78	4.44	7.73	28.01	4.03	0.42	0.93	0.52	0.14	2412		
2020-03	33.75	16.37	0.91	3.97	7.17	31.26	4.43	0.62	0.85	0.67	0.24	2252		
2020-09	23.78	3.72	0.72	4.45	9.31	52.64	2.38	0.52	1.24	1.24			15048	5620
2020-10	28.09	3.4	0.66	4.57	14.47	41.14	3.25	1.02	1.52	1.88			13838	4669
2020-11	25.7	4.86	0.69	5.49	16.38	39.38	4.81	0.54	0.74	1.42			10827	3399
2020-12	28.62	5.57	2.26	3.99	24.29	17.04	9.54	1.08	1.41	6.2			6941	2231
2021-01	30.1	7.17	1.16	5.27	22.84	20.55	7.01	0.69	0.61	4.61			5863	1916
2021-02	26.92	7.22	1.93	3.16	27.36	16.16	8.25	1.03	0.79	7.18			6548	2144
2021-03	28.41	10.07	1.9	3.15	25.88	12.75	8.74	1.33	0.68	7.1			6831	2238
2021-04	28.02	7.2	1.47	3.49	26.15	15.59	9.21	1.16	0.71	7			9845	3096
2021-05	28.18	6.98	1.53	3.58	27.92	14.68	8.37	1.67	1.11	5.98			9065	2841
$h_i^{rw}(\%)$	15	2	1	4	57	8	4	2	2	5				

Appendix C Estimating the infection status of departing travelers

The infection status of departing travelers is whether travelers are infected, and if infected, the number of days since exposure.

C.1 Infection prevalence at origin

C.1.1 Data sources - infection prevalence

The data source for new SARS-CoV-2 cases (incidence) was the Public Health Agency of Canada (PHAC) for the Canadian provinces (Public Health Infobase, 2020-2021). We assumed the daily infection incidence in the United States for all international travelers due to the lack of seroprevalence data for other countries. The Center for Systems Science and Engineering (CSSE) at Johns Hopkins University was the data source for the United States (Dong et al, 2020).

We used the method described in Martignoni et al (2023) to estimated the coefficient of under-reporting for COVID-19 in region i, by considered the cumulative percentage of the population that were seropositive for SARS-CoV-2 antibodies relative to the number of reported COVID-19 cases in a region, i. We assumed the under-reporting coefficient, u_i, for a given region did not change over time. The cumulative percentage of the population infected at the end of September 2020 and May 2021 is determined from seroprevalence data (Blood Donation Organizations, 2023; Centers for Disease Control and Prevention, 2020-2021) and divided by the cumulative reported cases for each region 13 days earlier because there are 9-12 days between symptom onset and seroconversion (Lou et al, 2020). The under-reporting coefficient, u_i, is calculated as the difference in the percentage of the population infected as estimated by the seroprevalence, divided by the difference in the percentage of the population reported as infected (table C7).

Table C7 Underreporting of COVID-19 cases

Region i	Population N_i	Cumulative reported cases to 2020-09-17	Cumulative reported cases per capita to 2020-09-17	Cumulative reported cases to 2021-05-16	Cumulative reported cases per capita to 2021-05-16	Seropositivity to 2020-09-30	Seropositivity to 2021-05-29	Estimated unreported cases per reported case
BC	5071336	7663	0.151%	139240	2.746%	0.5%	3.099%	1.002
AB	4371316	16274	0.372%	218961	5.009%	0.69%	5.27%	0.988
SK	1174462	1757	0.150%	44531	3.792%	0.14%	4.32%	1.148
MB	1369465	1500	0.110%	45149	3.297%	1.45%	5.37%	1.230
ON	14566547	45676	0.314%	509316	3.496%	0.85%	4.1%	1.021
QC	8484965	66356	0.782%	363296	4.282%	1.23%	4.84%	1.032
NS	971395	1086	0.112%	4736	0.488%	0.16%	0.23%	0.186
PEI	156947	57	0.036%	191	0.122%	0.142%	0.24%	1.148
TR	124460	20	0.016%	829	0.666%	0.12%	0.29%	0.262
NB	776827	194	0.025%	2063	0.266%	0.159%	0.172%	0.054
US	332660077	6704918	2.016%	33064172	9.939%	4.9%	20.6%	1.981

C.1.2 Estimating prevalence from incidence data

The travel volume from an origin is combined with the point prevalence at the travelers origin in our epidemiological model. To estimate point prevalence at the origin, we first estimate the incidence proportion at a traveler's origin, $f_i(t)$, on a day t,

$$f_i(t) = \frac{c_i(t + t_d)u_i}{N_i}, \tag{C6}$$

where $c_i(t)$ is the number of new cases reported on day t at the origin i, $t_d = 11$ days is the delay between exposure and reporting (we note that Hendy et al 2021 reports this delay can be over 2 weeks), N_i, is the population size for each origin, $i \in \{\text{INT, BC, AB, SK, MB, ON, QC, NB, NS, PE, TR}\}$ (based on 2021 values estimated from Statistics Canada 2021 and The United States government 2021), and u_i is an origin-specific correction factor to account for under-reporting.

We wish to convert from incidence proportion (the number of new cases divided by the population size) to prevalence (the proportion of the population that have infections at time t) because we assume that the probability a traveler has an active infection at departure is equal to infection prevalence at their origin. We assume that individuals have active infections for 14 days, and approximate point prevalence as $14f_i(t)$, where this calculation is not exact, it is an approximation. More exactly if prevalence was increasing until time t, then at time t more new infections than recoveries are occurring, such that the point prevalence is actually more than $14f_i(t)$ (and visa versa for decreasing incidence).

C.1.3 Infection status of departing travelers

In addition to knowing the probability that a traveler is infected, we also need to know the probability that it is a days since the traveler was exposed. We assume that the distribution of days since the exposure of infected travelers at departure is uniformly distributed as between 13 and 0 days ago, i.e.,

$$n_i(t, a) = \begin{cases} 14\frac{f_i(t)}{14} = f_i(t) & \text{for all } a = 0, 1, 2, \ldots, 13 \\ 0 & \text{otherwise,} \end{cases} \tag{C7}$$

where a is the number of days since exposure or the 'age' of infection. Again, this is an approximation because if incidence is increasing at time t, there will be more individuals with recent exposures, such that the distribution of age of infection is right-skewed (i.e., the tail is to the right as there relatively fewer individuals exposed many days ago). An approximation is used because estimating the distribution of the age of infections at any time from reported data is difficult since whether a case is reported depends on the age of the infection. This is because tests are requested once symptoms develop, and test results can be false negatives, and both of these depend on the age of infection. Due to development of symptoms and pre-arrival testing, not all infected travelers will end up travelling. If a pre-arrival test was required the rate of infected travelers arriving from the origin, i, that were exposed a days ago is,

$$\mathrm{T}_i^{k,1}(t,a) = v_i^k(t)(1 - t_{\mathrm{sens}}(a-2))n_i(t,a), \tag{C8}$$

where $v_i^k(t)$ is the travel volume from origin i of rotational workers ($k = rw$) or regular travelers ($k = r$) who departed on date t (see equations B3, B4, and B5), $1 - t_{sens}(a-2)$ is the probability of a false negative test for individuals exposed a days ago, where the test is assumed to occur 2 days before departure, when the infection prevalence at i is $n_i(t,a)$. The complete details of how we parameterized the probability of true PCR test, $t_{sens}(a)$, are provided in Appendix C.

It is assumed that individuals with symptoms that receive a false negative test result on a pre-departure test will still travel. When no pre-departure test is required, some travelers will not travel due to symptoms. The rate that infected travelers arrive from origin, i, that were exposed a days ago, when no pre-departure test is required is,

$$\mathrm{T}_i^{k,0}(t,a) = v_i^k(t)n_i(t,a)\rho\psi\Lambda(a), \tag{C9}$$

where travelers will develop symptoms with probability, ρ, will travel irrespective of symptoms with probability, ψ, and will first develop symptoms before departure (when their infection age is a at departure) with probability, $\Lambda(a)$ where,

$$\Lambda(a) = \sum_{\alpha=0}^{a} \lambda(\alpha) \tag{C10}$$

and,

$$\lambda(a) = \Gamma(a, \mathrm{shape} = 5.807, \mathrm{scale} = 0.948)\Delta a \tag{C11}$$

This parameterization is from (Lauer et al, 2020), and corresponds to first symptoms occurring a mean of 5.5 days after exposure with a standard deviation of 2.3 days (Hart et al, 2021). The probability density is discretized with $\Delta a = 1$ day because other data for our model occurs only at 1 day intervals. The cumulative mass function (equation C10) is because travelers that decided not to depart on date t, with infection age, a, may have first developed symptoms at any time 0 to a days after exposure.

In Canada, a pre-arrival test policy was enacted on January 7, 2021, for international travelers. Having a negative COVID-19 test result (72 hours prior to departure) was required for travelers departing from international ports (Government of Canada, 2020) and from May 15, 2021, it was necessary for all travelers (Traveler COVID-19 Testing 2021, see table D8). The rate that infected travelers arrived in NL with an infection of age, a is,

$$T_i^k(t,a) = \mathbb{1}_{\mathrm{PRE,i}}^k(t)\; T_i^{k,1}(t,a) + (1 - \mathbb{1}_{\mathrm{PRE,i}}^k(t))\; T_i^{k,0}(t,a), \tag{C12}$$

where $\mathbb{1}_{\mathrm{PRE,i}}^k(t)$ is an indicator variable that is equal to 1 if a pre-departure test is required for travelers of type k, departing from origin, i, at time t, and 0 otherwise.

Appendix D Post-arrival testing to identify travel-related cases

D.1 Testing of rotational workers

The final component of our epidemiological model is to consider post-arrival testing so that we can compare our model predictions with the reported number of travel-related cases in NL. From the early stages of the pandemic, there were specific post-arrival testing measures that applied to rotational workers (see table D8). The number of rotational workers that test positive on their first post-arrival test, occurring j_1 days after arrival from origin, i, and are reported as travel-related cases on day $t = t_t + j_1 + t_{rep}$ is,

$$R_i^{rw,1}(t_t + j_1 + t_{rep}) = \sum_{a=0}^{13} t_{\mathrm{sens}}(a + j_1) T_i^{rw}(t_t, a). \tag{D13}$$

where t_t is the date of departure, and is assumed to be the same day as arrival in NL. By the time the post-arrival test is completed, the days since exposure, a, for the infected traveler at time t, will have advanced by j_1 days from the time of departure, t_t, and the test results will not be reported for another $t_{rep} = 1$ days, which is the assumed delay between taking the test and having the result reported. The exposure date amongst travel-related cases is not reported, so we sum across all ages of infection between 0 and 13 days prior to departure.

Table D8 COVID-19 testing requirements for travellers arriving in Newfoundland and Labrador due to border measures implemented by the Government of Canada or Special Measures Orders issued by Newfoundland and Labrador.

Dates	Test policy
2020-09-09	Asymptomatic rotational workers are exempt from the requirement to self-isolate for 14 days if received a negative test between five and seven days after their return
2020-11-25	Rotational workers required to wait until day seven of their 14 day self-isolation period to arrange COVID-19 testing
2021-01-07	Requirement for mandatory negative COVID-19 test result for air passengers entering Canada announced (Federal measure)
2021-03-12	Domestic rotational workers; cease self-isolation if tested negative 3x (upon return, day 7 and on day 11,12 or 13)
2021-03-27	Updated rotational worker requirements: must isolate away from families for 14 days , cannot avail test on day 7 or modified self-isolation
2021-04-19	Essential workers entering the province required to self-isolate until they receive their 1st negative test result
2021-05-15	COVID-19 Testing order to Individuals arriving in NL (testing requirements during their 14-day self-isolation)

For positive results on the second and third post-arrival tests, occurring j_2 and j_3 days after arrival, but not any post-arrival tests prior,

$$R_i^{rw,2}(t_t + j_2 + t_{rep}) = \sum_{a=0}^{13}(1 - t_{\text{sens}}(a + j_1))t_{\text{sens}}(a + j_2)T_i^{rw}(t_t, a), \tag{D14}$$

$$R_i^{rw,3}(t_t + j_3 + t_{rep}) = \sum_{a=0}^{13}(1 - t_{\text{sens}}(a + j_1))(1 - t_{\text{sens}}(a + j_2))t_{\text{sens}}(a + j_3)T_i^{rw}(t_t, a), \tag{D15}$$

where the positive result for the second post-arrival test is reported at time $t = t_t + j_2 + t_{rep}$, and for the third post-arrival test is reported at time $t = t_t + j_3 + t_{rep}$.

Positive tests for rotational workers are calculated by summing results from all tests that were required, i.e.,

$$R_i^{rw}(t) = \sum_k R_i^{rw,k}(t). \tag{D16}$$

We do not consider tests for rotational workers based on developing symptoms when at least one post-arrival test was mandatory for rotational workers.

D.2 Travelers that develop symptoms after arrival

During the public health emergency, regular travelers arriving in NL were required to self-isolate. Regular travelers may have been reported as a travel-related case if they developed symptoms and requested a test. We assume that this test occurred t_r days after symptom onset, and if positive was reported $t_{rep} = 1$ day later,

$$R_i^{r,s}(t_t + t_{rep} + \bar{a} + t_r) = \rho P^S \sum_{a=0}^{13} T_i^r(t_t, a)t_{\text{sens}}(a + \bar{a} + t_r), \tag{D17}$$

where $T_i^r(t_t, a)$ is the rate that regular travelers arrive from i on day t_t with an infection of age a, ρ is the probability that infected travelers have symptomatic infections, and P^S is the probability that travelers with symptoms request a test. The mean time to develop symptoms for arriving travelers is $\bar{a}$ days after arrival, and the probability of a true positive test result t_r days later is $t_{sens}(a + \bar{a} + t_r)$. The mean time to developing symptoms after arrival is calculated as,

$$\bar{a} = \sum_{a=0}^{13}\sum_{a_t=0}^{13} a\lambda(a + a_t)p(a_t), \tag{D18}$$

where the probability that an arriving traveler has age of infection a_t is,

$$p(a_t) = \frac{\frac{1}{14}\left(1 - \rho(1-\psi)\Lambda(a)\right)}{\sum_{a=0}^{13} \frac{1}{14}\left(1 - \rho(1-\psi)\Lambda(a)\right)}. \tag{D19}$$

Since we only predict cases each day, and $t_{sens}(a)$ is a discrete function defined each day, $\bar{a}$ from equation D18 is rounded to the nearest integer before being used in Equation D17.

The probability of infections of age a_t amongst arriving travelers is calculated assuming that exposure times for travelers are uniformly distributed as 0 to 13 days before departure, and that $1-\psi$ travelers that develop symptoms before departure will not travel. The average timing of first symptoms after arrival is calculated assuming no pre-departure test. As some travelers do not travel due to symptoms, the distribution of age of infection in arriving travelers is skewed right (i.e., the tail is to the right) because more arriving travelers were exposed shortly before to departure.

The use of $\bar{a}$ in equation D17 is an approximation because, more exactly, a traveler arriving on day t_t with infection age a might first show symptoms on any of the days post-arrival (14 possible days). For our model, there are 273 possible arrival days (September 1, 2020 to May 31, 2021) and 14 possible ages of infection at arrival, which means that it is necessary to calculate 3,822 values corresponding to each arrival date and age of infection. If we consider that travelers might first develop symptoms on any of the 14 days they are in self-isolation after arrival, then the number of calculations necessary increases to 53,508. To reduce the number of calculations needed, we assume that all arriving travelers first experience symptoms $\bar{a}$ days after arrival, where the value of $\bar{a}$ has some epidemiological basis (see equation D18), but is assumed equal for all travelers irrespective of when they were exposed.

D.3 Asymptomatic regular travelers

Arriving regular travelers with asymptomatic infections might also be detected as travel-related cases because NL public health, at times, issued exposure notifications and asked all travelers arriving on particular flights to arrange for PCR testing (see Table D9 in Appendix C). As noted previously, a large proportion of arrivals to NL are by air. Such flight notifications would mostly detect individuals infected on the flight rather than prior to departure (i.e., infection age $a = 0$ at time, t_t). Therefore, the number of arriving regular travelers detected due to exposure notifications is,

$$R_i^{r,e}(t_t + t_r + t_{rep}) = v_i^r(t_t) P_i^A t_{sens}(t_r + t_e), \tag{D20}$$

where $v_i^r(t_t)$ is the volume of regular travelers arriving on day t_t from origin i, and P_i^A is the probability that travelers are infected during a flight and comply with the request to complete testing, where it is assumed that exposure notifications are issued t_e days after arrival and travelers are tested t_r days after requesting a test, such that the probability of a positive test result if infected is $t_{sens}(t_r + t_e)$. In NL, close contacts of travelers that were required to undergo asymptomatic testing were reported as such, and were not included in the number of cases reported as travel-related. We consider only regular travelers in the travel volume, as for much of the public health emergency in NL, rotational workers were required to complete post-arrival tests (Table D8). Equation D20 assumes that regular travelers that were exposed on flights were not infected prior to departure. While this is an approximation with few exposure notifications it is unlikely that our equations will result in substantial double counting of infected individuals because we counted these individuals both as infected during a flight, and infected pre-departure.

D.4 Reported travel-related cases

Finally, the predictions of the epidemiological model are compared with the number of travel-related cases reported as originating from Canada or internationally. For travelers from international origins this is,

$$R_{\text{INT}}(t) = R_{\text{INT}}^{r,e}(t) + R_{\text{INT}}^{r,s}(t), \tag{D21}$$

and for travelers from Canadian origins this is,

$$R_{\text{CA}}(t) = \sum_i R_i^{r,e}(t) + R_i^{rw}(t) + R_i^{r,s}(t), \tag{D22}$$

where the sum i is across all Canadian provinces and territories. An overview of the model and summary of parameters is given in Figure A1 and Tables A1.

Table D9 Exposure notification from Public Health Advisories in NL during the COVID-19 pandemic where passengers on arriving flights were asked to arrange COVID-19 testing (Government of Newfoundland Labrador, 2023).

Date	Exposure notification to passengers
2020-09-27	WestJet Flights 306 and 328 departing Winnipeg and Toronto
2020-10-05	Air Canada Flight AC8876 departing Halifax for Deer Lake
2020-10-05	Air Canada Flight AC604 departing Toronto
2020-10-23	Air Canada Flight 7484 from Toronto
2020-11-04	Air Canada Flight 7484 from Toronto
2020-11-23	Air Canada Flight 8880 from Halifax
2020-11-24	People who have returned to Newfoundland and Labrador from Nova Scotia in the last two weeks, and who visited bars in Halifax and surrounding metro communities
2020-12-04	WestJet Flight 3428 from Halifax
2020-12-20	Several flight advisories this weekend: Air Canada Flight 8862 from Halifax to Gander arrived Monday, December 7 Air Canada Flight 690 from Toronto to St. John's arrived Friday, December 11 Air Canada Flight 8862 from Halifax to Gander arrived Friday, December 11 Air Canada Flight 8862 from Halifax to Gander arrived Tuesday, December 15 Air Canada Flight 690 from Toronto to St. John's arrived Tuesday, December 15 Air Canada Flight 690 from Toronto to St. John's that arrived Thursday, December 17
2020-12-29	Air Canada Flight 8880 from Halifax to Deer Lake
2021-01-20	Who traveled on the MV Blue Puttees to and from North Sydney, Nova Scotia, and Port Aux Basques
2021-02-15	Air Canada Flight 7484 that departed Toronto
2021-03-04	Air Canada Flight 8996 that departed Halifax
2021-04-19	Air Canada Flight 8008 that departed Toronto
2021-05-02	Air Canada Flight 8016 that departed Montreal
2021-05-06	Air Canada Flight 7540 that departed Toronto
2021-05-11	Air Canada Flight 7542 that departed Toronto

Appendix E Statistical models

The statistical models described in table 1 are general linear models where the response variable is either the daily travel-related cases reported in NL from Canadian or international origins. The models considered have explanatory variables which are daily infection prevalence at origin (see Appendix C.1) or daily total travel volume from an origin (see Appendix B.1). We also considered the product of daily infection prevalence and travel volume for a given origin. Origins that we considered were: Provinces, which consisted of each non-NL Canadian province and the Canadian territories (where all three territories were combined); Canada, where the travel volume of any non-NL Canadian origin was summed, and infection prevalence was an average for all of Canada; and International where travel volumes were from any country outside of Canada and infection prevalence was assumed equal to that of the United States.

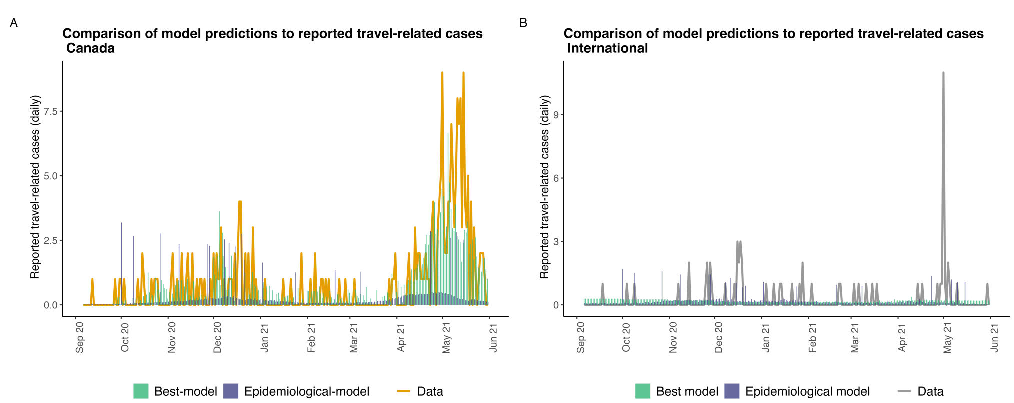

Fig. E2 The predicted reported travel-related cases arriving in NL (daily) for the epidemiological model (blue bars) and the best model (green bars; see table 1) for travelers originating from (A) Canadian and (B) international origins. In both, A and B daily travel-related cases reported in NL are shown with lines.

Appendix F Validation data: travel-related cases for Newfoundland and Labrador

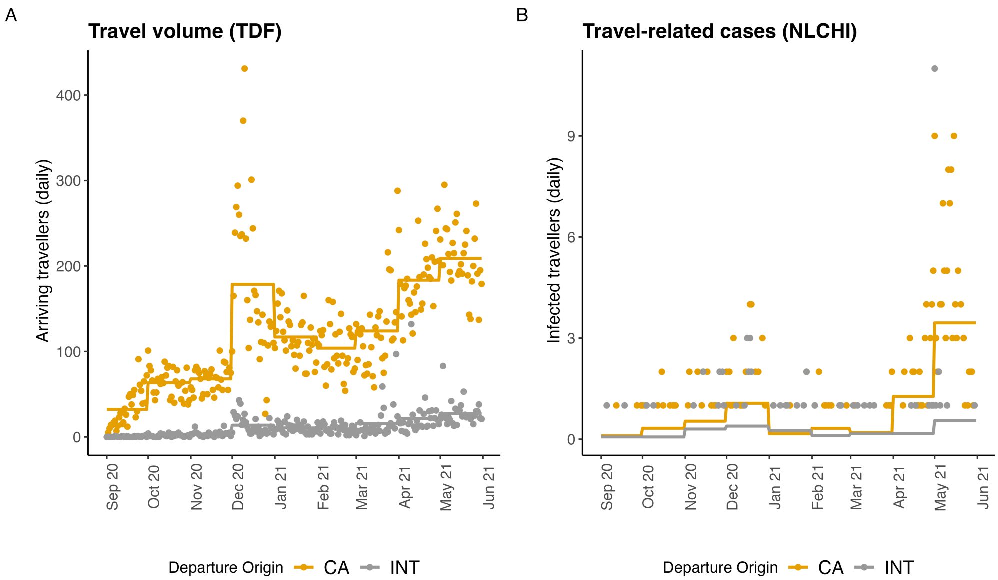

Fig. F3 Travel volume is a variable included in several of our models and may affect the number of travel-related cases reported in NL (September 2020 to May 2021; Canada - yellow; international - grey). A. Travel volume of non-exempt travelers arriving in NL as reported by the TDF. B. Travel-related cases reported in the NLCHI COVID-19 database. Both daily values (dots) and monthly averages (lines) are shown.

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