

Estimated health and economic benefits in Canada of reduced tuberculosis transmission in key source countries of immigration: a Markov modelling analysis

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Abstract

Background

Tuberculosis remains the leading cause of death due to a single infectious agent globally, responsible for 1.23 million deaths in 2024 alone. In Canada, approximately 80% of people who develop tuberculosis disease are foreign-born, typically reflecting the progression of tuberculosis infection acquired prior to immigration. Overseas investments in tuberculosis prevention and care programs in high-burden, key-source immigration countries may therefore represent a valuable strategy for improving tuberculosis epidemiology among foreign-born Canadians. We aimed to quantify the potential downstream impacts of improved tuberculosis epidemiology overseas on tuberculosis-related outcomes among foreign-born Canadians.

Methods

An open-cohort Markov microsimulation model was used to simulate tuberculosis epidemiology among foreign-born Canadians between 2001 and 2050. We modelled a status quo scenario and four reduction scenarios where additional 1–4% reductions in annual risk of tuberculosis infection were applied to current trends among foreign-born individuals from China, India, the Philippines, and Vietnam beginning in 2025 and continuing until 2050. Key outcomes included Canadian healthcare system costs, tuberculosis infection cases, tuberculosis disease cases, tuberculosis deaths, and quality-adjusted life years. Incremental net monetary benefit was calculated using a willingness-to-pay threshold of \$100,000 per quality-adjusted life year gained.

Results

The largest health and economic gains between 2025 and 2050 were predicted among foreign-born individuals from India and the Philippines. The number of tuberculosis cases averted among foreign-born individuals from India ranged from 68 to 230 in the 1% and 4% reduction scenarios, respectively, compared to 73 and 246 cases averted among those from the Philippines. Incremental net monetary benefit was highest among individuals from India (\$3.4–12 million with 1–4% reductions), followed by those from the Philippines (\$2.4–8.6 million). Incremental net monetary benefit was predicted to be substantially lower among individuals from China (\$0.8–2.6 million) and Vietnam (\$0.1–0.3 million).

Conclusion

Our findings suggest that improvements in tuberculosis epidemiology in high-burden, key-source immigration countries—particularly India and the Philippines—have the potential to generate meaningful downstream economic and health benefits among foreign-born Canadians. Moreover, the gains achieved

in Canada would represent only a portion of the larger global benefit. Future modelling work should focus on identifying specific interventions capable of achieving such benefits in a cost-effective manner.

Introduction

Tuberculosis (TB) remains the leading global cause of death due to a single infectious agent, with over 10.7 million persons developing TB disease and a resulting 1.23 million deaths every year.¹

Mycobacterium tuberculosis (*Mtb*), the causative agent of TB, is estimated to have infected about one quarter of the world's population.²

In line with goals outlined by the World Health Organization (WHO), the Public Health Agency of Canada (PHAC) has committed to reducing TB incidence to < 1 case per 100,000 population by 2035.³ However, after remaining essentially unchanged since the 1980s, TB incidence is now increasing in Canada, and novel strategies are urgently required to meet WHO and PHAC goals.^{4, 5} TB disease incidence in Canada was 6.1 cases per 100,000 population in 2024—a 10% increase over 2023 and 33% increase from 2015.⁶ In 2024, > 80% of individuals newly diagnosed with TB disease in Canada were born outside of Canada, with most developing disease due to progression of TB infection acquired prior to immigration.^{6–8}

Though the reported TB incidence rate among foreign-born Canadians is 17.4 per 100,000 persons, very few have acquired TB infection within the preceding two years (approximately 1 in 2000)—the period at highest risk for progression to TB disease.⁹ Thus, most people born outside of Canada are at low risk of TB disease progression; accordingly, mass TB infection screening and treatment programs in Canada have been found to be largely cost-prohibitive.⁹ Investing in overseas TB prevention and care programs represents a potential supportive approach to eventual TB elimination in low-incidence countries like Canada.¹⁰ Improved TB programs in high-burden, key-source immigration countries can potentially reduce morbidity and mortality in Canada by lowering the prevalence of TB infection among future immigrants.^{11, 12} For example, program improvements could involve enhanced case detection (e.g., active case finding), expanded coverage and uptake of TB preventive treatment (TPT) among high-risk individuals, improved diagnostic and treatment methods (e.g., more accurate diagnostic tests or shorter treatment regimens), and/or a more effective TB vaccine.^{11, 13, 14}

Without explicitly considering any specific intervention, we aimed to predict more broadly the impact of potential reductions in TB infection prevalence among immigrants from high TB-incidence countries on TB epidemiology and outcomes in Canada from 2025–2050. We focus on immigrants from China, India, the Philippines, and Vietnam since approximately 40% of new immigrants to Canada come from these countries, and they bear over 60% of the TB burden among Canadians born outside of Canada.¹⁵

Methods

Overview

We developed an open-cohort Markov microsimulation model to simulate TB epidemiology among foreign-born Canadians between 2001 and 2050.⁹ Trends in TB infection prevalence among new immigrants to Canada by age at immigration and country of origin were estimated previously.^{9, 16} These estimates are based on annual risk of TB infection (ARI) trajectories in 168 countries constituting >99% of new immigrants to Canada. In brief, these previous studies leveraged 200 different ARI projections from 2000-2021 to estimate an average annual change in ARI during this period and applied this same change from 2022-2050. These estimated TB infection prevalence trends captured what would be expected, and attendant uncertainty in this expectation, in absence of intervention and therefore constituted our status quo scenario.

Our main objective was to understand how changes in TB epidemiology in China, India, the Philippines, and Vietnam would impact TB-related costs and outcomes in Canada. In 2017—the most recent year country of origin among TB episodes was available in Canada—the Philippines, India, China, and Vietnam were the most frequently reported countries of origin, constituting 21%, 20%, 14%, and 5% of TB episodes among people born outside of Canada, respectively.¹⁵ Thus, we simulated scenarios where TB epidemiology would improve in these four countries, while remaining unchanged in all others. Improvements in TB epidemiology were operationalized as reductions in the annual risk of TB infection (ARI) in China, India, the Philippines, and Vietnam, which is directly related to TB infection prevalence. Using the projected average annual change in ARI in these four countries from 2000-2021, we further reduced the annual change in ARI beginning in 2025 by an absolute 1%, 2%, 3%, or 4% reduction, creating four reduction scenarios.

For the status quo and each reduction scenario, we estimated TB-related outcomes among immigrants from the four countries expected to enter Canada from 2025-2050. For the various reduction scenarios, we estimated incremental differences compared with the status quo. All modelling was conducted using TreeAge Pro Healthcare 2025 R1.1 (TreeAge, Williamstown, Massachusetts, USA), while all subsequent data analyses were performed using R 4.5.0 (The R Foundation for Statistical Computing, Vienna, Austria).

Population Modelled

The Markov model simulates an open cohort of Canadian permanent residents and citizens born outside of Canada covering the period from 2001 to 2050. Individuals enter this open cohort upon immigration to Canada and exit upon death or emigration. For 2001-2021, the size and demographic characteristics of the cohort reflect data from the 2001, 2006, 2011, 2016, and 2021 Statistics Canada censuses. These data report the numbers of individuals born outside of Canada as well as their countries of origin, years since arrival in Canada, and ages, grouped into four age categories: 0–14, 15–24, 25–64, and ≥65 years of age. Within each category, we assumed a uniform age distribution. The most recent Canadian census (2021) reported a total population of 8.3 million citizens and permanent residents born outside of

Canada. The full population data is available in the supplement (**Table A1**), reproduced from Jordan et al.⁹ The countries included in this analysis are provided in **Table A2**.

We determined the number of individuals from each country of origin who entered and left Canada from 2001 to 2021 using data from Immigration, Refugees, and Citizenship Canada (IRCC) and Canadian census data.¹⁷ IRCC data contain information regarding the number of permanent residents that migrate to Canada each year by country of origin. To estimate the number of entrances and exits between 2022 and 2050 from each country, we extrapolated immigration trends observed from 2001 through 2021.

A total of 10.9 million new permanent residents were predicted to enter Canada between 2025 and 2050. Of these, 1.2 million permanent residents were predicted to arrive from China, 1.3 million from India, 1.7 million from the Philippines, and 0.1 million from Vietnam (**Figure A1**).

Probability of Tuberculosis Infection

To estimate the probability of TB infection among immigrants, we leveraged our estimates of the annual rate of change in the ARI among persons immigrating from 168 countries between 2000 and 2021 across 200 probabilistic simulations.^{9, 18} Under the status quo scenario, these rates of change were then applied from 2022-2050 to generate a predicted ARI within each country each year while propagating uncertainty. Then, for each immigrant entering each year, we estimated the cumulative probability of TB infection at arrival, based on their mean estimated risk of infection every year until that time, with 95% uncertainty ranges estimated as the 2.5th and 97.5th percentile across the 200 probabilistic simulations. Within the 1%, 2%, 3%, and 4% reduction scenarios, we considered that additional annual reductions in the ARI would be superimposed on the assumed continuation of previously observed trends. For example, if the ARI among foreign-born individuals from a given country was declining at an average rate of -2% per year prior to 2025, the adjusted rate of decline beginning in 2025 would be -3%, -4%, -5%, and -6% per year in the 1%, 2%, 3%, and 4% reduction scenarios, respectively. Additional details are provided in the **Appendix**.

Tuberculosis Natural History, Testing, and Treatment

On arrival in Canada, immigrants may have no infection, TB infection, or TB disease. We assume no transmission within Canada, and so individuals immigrating without infection remain in this state unless they exit the model (through background mortality, or emigration from Canada). Individuals who arrive with TB infection remain with TB infection until they exit, progress to TB disease, or are successfully treated for TB infection. Individuals who arrive with or develop TB disease are detected and treated in the year they develop TB disease.

All potential immigrants to Canada are screened for TB disease during the application process and must be treated if TB disease is identified. However, TB infection screening is rarely done, except for the small

number of immigrants with HIV infection, end-stage renal disease, or a history of close TB contact. As such, only an estimated 0.4% of new entrants are screened for TB infection and referred for post-arrival evaluation and potential treatment.¹⁹ The remainder remain untested and untreated for TB infection, as there are no systematic post-arrival TB infection programs in Canada.

The small number of entrants who screen positive for TB infection undergo medical evaluation to rule out TB disease, and if no TB disease is found, TB infection treatment with four months of daily oral rifampin is typically offered, which may be accepted or refused. Those on treatment may experience adverse events, which impacts health utility. TPT efficacy was parameterized as 90% among those completing and 21% among those not completing.²⁰⁻²² The probability of progressing from TB infection to TB disease reflected previous calibration of this parameter to reported TB disease incidence among foreign-born Canadians.²³ Annual progression probabilities vary accordingly by WHO region of origin, with specific annual progression probabilities in the year of arrival for our countries of interest shown in **Table 1**.²⁴ Those who develop TB disease experience one of four outcomes: death from TB disease or its treatment, loss to follow-up, treatment failure, or treatment success. If treatment is successful, they are cured of TB disease and move to the “recovered” state. If treatment fails, retreatment occurs. A simplified overview of the Markov decision analysis model is shown in **Figure 1**, while a more detailed overview is shown in **Figure A2**.

Utility Weights and Cost Inputs

For estimates of QALYs, TB-related utility weights reflected a study of persons treated for TB disease and for TB infection, as well as a control group with similar demographics, in Montreal, Canada.²⁵ Cost parameters reflected a published study of Canadian TB-related health care costs.²⁶ Importantly, we did not attribute any “incurred costs” for the improvements in TB epidemiology in China, India, the Philippines, or Vietnam for these scenarios, as we wished to estimate the potential value of such epidemiological improvements in Canada, which could help justify the costs to Canada and similar countries of investment in TB care abroad. Details of utility and cost inputs are in **Table 1** and **Table A3**.

Analyses

Modeled outcomes included expected numbers of immigrants with TB infection, those developing TB disease, TB-related deaths, QALYs, and TB-related health system costs. All costs were expressed in 2025 Canadian dollars, using inflation rates reported by the Bank of Canada for costs reported from earlier years.²⁷ For each ARI reduction scenario for each source country, we estimated incremental and relative differences in these outcomes, as compared to the status quo. Next, to understand the impact of TB epidemiology changes in the four countries on overall TB morbidity and costs in Canada, we estimated these same incremental and relative differences considering all new immigrants to Canada. Finally, we estimated the incremental net monetary benefit (INMB) for each reduction scenario, using a

willingness-to-pay threshold of \$100,000 per QALY gained, to approximate how much a country like Canada might potentially be willing to invest to obtain the ARI reductions modeled. All outcomes incorporating costs (healthcare system costs and INMB) from 2025-2050 were discounted by 1.5% annually,²⁸ while epidemiological outcomes (TB infections, TB disease episodes, TB deaths, and QALYs) were not discounted.

For all outcomes, we report means, and 95% uncertainty ranges (2.5th and 97.5th percentiles) obtained from probabilistic analyses reflecting 1000 Monte Carlo simulations, with sampling from the input parameter distributions listed in **Table 1**. Parameters associated with TBI screening and treatment were excluded from our probabilistic analysis since this analysis does not look at enhanced domestic screening programs and very few foreign-born permanent residents are screened for TBI in Canada. These fixed TBI parameters are available in **Table A3**. Similarly, parameters related to TB disease treatment outcomes were held constant based on the observed 2023 treatment outcomes among foreign-born Canadians, as reported by the Public Health Agency of Canada and the Canadian Tuberculosis Reporting System.²⁹

Table 1: Key Epidemiological Parameters.

Annual Risk of Tuberculosis Infection				
Country of Origin	Mean Value (95% UR)			Reference
	2000	2021	Rate of Change	
China	0.5% (0.3–0.7%)	0.2% (0.1–0.5%)	-3.6% (-7.0–0.2%)	Calculated
India	1.3% (0.8–1.8%)	0.6% (0.3–1.0%)	-3.8% (-6.8–-0.2%)	Calculated
Philippines	2.2% (1.3–3.4%)	1.2% (0.6–2.2%)	-2.9% (-6.8–0.7%)	Calculated
Vietnam	1.0% (0.6–1.7%)	0.5% (0.2–1.2%)	-3.5% (-8.4–1.5%)	Calculated
All other countries	0.5% (0.3–0.8%)	0.3% (0.1–0.7%)	-2.1% (-6.5–2.4%)	Calculated
Probability of Tuberculosis Infection Immediately Preceding to Canada				
Country of Origin	Mean Value (95% UR)			Reference
	2001	2025	2050	
China	27.0% (9.7–42.6%)	13.1% (8.9–17.5%)	6.1% (3.3–9.7%)	Calculated
India	31.3% (22.7–38.9%)	23.3% (18.9–28.1%)	12.3% (5.4–21.9%)	Calculated
Philippines	51.1% (26.8–66.5%)	36.7% (28.4–44.4%)	22.1% (8.4–41.4%)	Calculated
Vietnam	46.5% (10.0–70.8%)	24.8% (13.2–32.9%)	11.6% (4.1–22.3%)	Calculated
All other countries	28.0%	11.2%	7.7%	Calculated

(10.0–60.0%)	(6.9–17.0%	(1.9–18.0%)
Annual Probability of TB Infection Progression to TB Disease		
Country of Origin	Mean Value (95% UR)	Reference
China	0.2% (0.1–0.3%)*	Calculated
India	0.4% (0.2–0.6%)*	Calculated
Philippines	0.2% (0.1–0.3%)*	Calculated
Vietnam	0.2% (0.1–0.3%)*	Calculated
All other countries	0.3% (0.1–0.4%)*	Calculated
Tuberculosis Disease Treatment Parameters		
Parameter	Value	Reference
Probability of cure following complete TB disease treatment	84.4%	29
Probability of TB disease treatment failure	0.3%	29
Probability of loss to follow-up during TB disease treatment	7.8%	29
Probability of death from TB disease before or during treatment	7.4%	29
Probability of cure after loss to follow-up during TB disease treatment	25%	30, 31
Annual probability of relapse after successful TB disease treatment (experienced for two years)	1.5%	25, 32-37
Health Utility Parameters		
Parameter	Value (95% CI)	Reference
Utility value for healthy individuals and those with TB infection	0.81 (0.69–0.91)	25
Utility value decrement for individuals with TB disease (experienced for three months)	0.12 (0.05–0.21)	25
Utility value decrement for major adverse events during TB infection treatment (experienced for half a month)	0.21 (0.13–0.31)	25
Healthcare System Cost Parameters		
Parameter	Value (95% CI)	Reference
Cost of complete TB disease treatment	\$22,739	26

	(\$3,146–\$57,725)	
Cost of incomplete TB disease treatment	\$19,891	26
	(\$11,727–\$30,783)	
Cost of death due to TB disease	\$31,404	26
	(\$9,083–\$68,412)	

Abbreviations: TB, tuberculosis; UR, uncertainty range; CI, confidence interval

* The probability of disease progression from TBI to TB disease is reduced to 50%, 50%, 40%, 30%, and 25% of the listed value after the first, second, third, fourth, and fifth year in Canada, respectively, and then remains at 20% of the listed value in all subsequent years

Results

Probability of Tuberculosis Infection

Across the 200 ARI projections between 2000 and 2021, the estimated average annual rate of change in ARI was -3.6% (falling from a mean of 0.5% in 2000 to 0.2% in 2021) among persons arriving from China, -3.8% (falling from a mean of 1.3% in 2000 to 0.6% in 2021) among persons arriving from India, -2.9% (falling from a mean of 2.2% in 2000 to 1.2% in 2021) among persons arriving from the Philippines, and -3.5% (falling from a mean of 1.0% in 2000 to 0.5% in 2021) among persons arriving from Vietnam (**Table 1, Figure A3**). These trajectories led to mean TB infection prevalence in the status quo falling from 27.0% in 2001 to 13.1% in 2025 and 6.1% in 2050 among individuals from China, from 31.3% in 2001 to 23.3% in 2025 and 12.3% in 2050 among individuals from India, from 51.1% in 2001 to 36.7% in 2025 and 22.1% in 2050 among individuals from the Philippines, and from 46.5% in 2001 to 24.8% in 2025 and 11.6% in 2050 among individuals from Vietnam (uncertainty reported in **Table 1; Figure A4**). Additional annual reductions in ARI were predicted to lower TBI prevalence to 3.9% (95% UR: 3.4–4.6%), 8.5% (6.9–10.1%), 15.9% (13.5–20.9%), and 7.9% (6.7–10.1%) in 2050 in the 4% reduction scenario among foreign-born permanent residents from China, India, the Philippines, and Vietnam, respectively (**Figure 2; Figure A4**). The TBI prevalences predicted in the 1–3% reduction scenarios are shown in **Figure 2** (uncertainty reported in **Figure A4**).

If the status quo persists, the predicted numbers of TB disease episodes spanning 2025–2050 would be 1,711 (1,617–1,806) among immigrants from China, 6,911 (6,702–7,124) among immigrants from India, 5,329 (5,138–5,513) among immigrants from the Philippines, and 240 (95% UR: 227–253) among immigrants from Vietnam (**Figure 3; Table A4**). TB-related costs to the Canadian healthcare system between 2025 and 2050 were predicted to be lowest among new permanent residents from Vietnam and highest among those from India, albeit with very wide 95% uncertainty ranges. These costs were

predicted to be \$39 million (\$12–84 million), \$157 million (\$50–343 million), \$121 million (\$39–265 million), and \$5 million (95% UR: \$2–12 million) among all new permanent residents from China, India, the Philippines, and Vietnam, respectively (**Figure 3; Table A4**).

In the 1–4% reduction scenarios, new immigrants from the Philippines and India were projected to experience the greatest health gains and cost savings (**Table 2; Table A5**). Between 2025 and 2050, the number of TB disease episodes averted among new immigrants from the Philippines was 73 (95% UR: 65-80) in the 1% reduction scenario and 246 (223-273) in the 4% reduction scenario, with corresponding episodes averted of 68 (63-73) and 230 (214-247) among immigrants from India (**Table 2**). Notably, new immigrants from India were projected to experience larger QALY gains than those from the Philippines, despite having fewer TB disease cases averted; individuals from the Philippines were predicted to gain 9.7 (5.9–14.7) in the 1% reduction scenario and 37.4 (23.8–55.3) in the 4% reduction scenario, compared to 20.7 (16.6–25.5) and 74.0 (60.0–90.7) for individuals from India (Table 2). These discrepancies reflect the higher probability of disease progression—and thus earlier presentation of TB—among those from India, providing larger QALY gains per episode averted.

We predicted the INMB was highest among individuals from India, followed by those from the Philippines (**Figure 4; Figure A5**). The INMB predicted among all new immigrants from India between 2025 and 2050 ranged from \$3.4 million (95% UR: \$2.4–5.1 million) with a 1% reduction to \$12.0 million (\$8.4–17.7 million) with a 4% reduction, while corresponding numbers among new immigrants from the Philippines ranged from \$2.4 million (\$1.3–4.2 million) to \$8.6 million (\$4.9–14.8 million).

INMB was predicted to be substantially lower among individuals from Vietnam and China due to relatively smaller numbers of new immigrants arriving from Vietnam, and the already low TB infection prevalence among people immigrating from China. Among new immigrants from Vietnam, predicted INMB was \$0.1 million (95% UR: \$0.1–0.1 million) with a 1% reduction and \$0.3 million (\$0.2–0.5 million) with a 4% reduction, while among immigrants from China, predicted INMB was \$0.8 million (\$0.5–1.1 million) and \$2.6 million (\$1.0–3.7 million), with 1% and 4% reductions, respectively.

Table 2: Predicted incremental tuberculosis-related outcomes among foreign-born Canadians between 2025 and 2050 by country of origin.

	Scenario	Healthcare System Costs Averted (2025 CAD) (95% UR)	TB Disease Cases Averted (95% UR)	QALYs Gained (95% UR)
China	1% Reduction	\$266,892 (\$86,030–\$583,388)	13.5 (12.8–14.2)	4.8 (3.9–5.9)
	2% Reduction	\$499,757 (\$161,209–\$1,093,317)	25.1 (23.9–26.5)	9.3 (7.6–11.3)
	3% Reduction	\$706,423 (\$227,456–\$1,547,384)	35.5 (33.7–37.4)	13.4 (10.9–16.2)
	4% Reduction	\$892,720 (\$287,037–\$1,956,541)	44.7 (42.5–47.1)	17.3 (14.1–20.8)
India	1% Reduction	\$1,347,891 (\$431,556–\$2,959,970)	68.0 (63.1–73.0)	20.7 (16.6–25.5)
	2% Reduction	\$2,556,571 (\$818,077–\$5,613,044)	128.7 (119.4–138.0)	40.0 (32.3–49.2)
	3% Reduction	\$3,625,743 (\$1,159,810–\$7,961,483)	182.2 (169.2–195.3)	57.6 (46.6–70.8)
	4% Reduction	\$4,585,415 (\$1,466,999–\$10,068,018)	230.1 (213.7–246.5)	74.0 (60.0–90.7)
Philippines	1% Reduction	\$1,436,539 (\$462,835–\$3,156,819)	72.5 (65.4–80.4)	9.7 (5.9–14.7)
	2% Reduction	\$2,719,532 (\$876,683–\$5,976,290)	137.0 (123.8–152.0)	19.2 (11.9–28.8)
	3% Reduction	\$3,875,148 (\$1,248,817–\$8,517,335)	194.9 (176.2–216.0)	28.4 (17.9–42.4)
	4% Reduction	\$4,899,696 (\$1,578,844–\$10,768,660)	246.1 (222.6–272.6)	37.4 (23.8–55.3)
Vietnam	1% Reduction	\$43,678 (\$13,913–\$97,166)	2.2 (2.0–2.4)	0.4 (0.3–0.6)

2% Reduction	\$82,481	4.1	0.8
	(\$26,272–\$183,323)	(3.7–4.5)	(0.6–1.1)
3% Reduction	\$116,797	5.8	1.2
	(\$37,207–\$259,665)	(5.3–6.4)	(0.8–1.6)
4% Reduction	\$147,648	7.4	1.5
	(\$47,044–\$328,246)	(6.7–8.1)	(1.1–2.1)

Discussion

Our analysis reinforces previous suggestions that overseas investments in TB prevention and care represent a promising strategy towards TB elimination in low-incidence, immigrant-receiving countries like Canada, where most TB disease occurs in people born outside of Canada who largely acquired their infection before immigration.^{10, 11, 38, 39} This is consistent with previous work demonstrating that improvements in global TB prevention and care generate strong economic returns for high-income countries.¹⁰ Indeed, previous analyses also suggest that every \$1 invested in global TB prevention and care generates \$46 worth of downstream economic returns.⁴⁰ Not surprisingly, potential health gains and cost savings will be greatest in countries where the current TB incidence is highest.

Our analysis also highlights the impact of reductions in TB disease incidence, and hence TB infection prevalence, already ongoing in some key countries. The benefits of such improvements extend beyond the countries directly involved to other countries that receive a large number of immigrants, such as Australia and the United States.⁴¹ In 2023, Canada received only 40% of all new immigrants from China, India, the Philippines, and Vietnam that arrived in Canada, Australia, or the United States.⁴² Thus, while the INMBs estimated herein may seem small, they only represent Canada's share of the much larger potential global benefit. Indeed, studies in Australia and the United States have predicted that investments in TB prevention and care programs in high-burden countries yield larger economic and health benefits than domestic programs.^{39, 43-45}

Conversely, reductions in TB-related spending and care will have widespread consequences. Between 2015 and 2024, the United States was responsible for approximately 50% of all international donor funds for TB through its contributions to the Global Fund and the United States Agency for International Development (USAID).¹ However, the United States has since dismantled USAID and stated its intention to cut TB program spending by \$228 million in 2026, representing a 55% decrease from funding levels in 2024 and 2025.^{46, 47} An additional \$1.35 billion approved by the United States Congress to support TB, malaria, HIV, and maternal and child health programs is also being withheld by the United States Government Office of Management and Budget.⁴⁸ Group of Seven (G7) countries are likewise expected to reduce foreign aid spending by 28% in 2026 compared to 2024, the largest cut in foreign aid spending since the G7 was formed in 1975.⁴⁹ Modeling analyses have estimated that the announced cuts will

result in 5.3 million additional TB disease episodes and 1.9 million additional TB deaths globally by 2035.⁵⁰ We can anticipate that additional TB disease episodes abroad will ultimately lead to an increase in Canadian TB incidence.

Nonetheless, the countries on which we focused have undertaken important initiatives. For example, in 2020, the Philippines committed to expanding TPT coverage to include all household contacts, not just those under the age of five.⁵¹ In India, the National Strategic Plan 2017–2025 for TB Elimination emphasizes shorter treatment regimens, expanded TPT coverage, and enhanced case detection efforts.⁵² Likewise, enhanced case detection and screening programs, particularly among high-risk populations, represent promising strategies for improving TB epidemiology in Vietnam.⁵³ Indeed, over the past decade, such efforts have led to a 25% decrease in TB incidence in China, a 21% decrease in India, and a 9% decrease in Vietnam, according to WHO TB registry data, although TB incidence continues to increase in the Philippines, rising 13% in the last decade.¹

Our analysis took advantage of a complex Markov microsimulation model, calibrated to recent TB epidemiology in residents and citizens born outside of Canada.²³ The immigration and TB surveillance data used for calibration came from IRCC, Statistics Canada, and the Public Health Agency of Canada. However, temporary residents—including students, seasonal workers, and tourists—are not captured in the source data, which also have limited information regarding covariates such as sex and immigration category. We also assumed that current immigration trends would continue through 2050. If entrant numbers from each country change, but their characteristics remain otherwise similar, this would not affect per capita estimates of health gains and cost savings, but would impact overall TB morbidity, mortality and cost. On the other hand, changes in age at migration and/or other medical or social risk factors for TB infection and progression would alter our per capita projections. For example, if future immigration shifts to favour family reunification, and hence potentially older migrants, this could increase background risks of TB infection and progression. On the contrary, a larger focus on economic class immigration may shift risk lower due to a younger, generally healthier population, as has been the case in Canada in recent years.⁵⁴

We also made the simplifying assumption that all immigrants of the same age and country of origin have the same probability of antecedent TB infection if they arrive in the same year. Our model did not specifically account for comorbidities, but these are addressed implicitly in its calibration. We did not incorporate excess post-TB morbidity and mortality in our model; their inclusion would have increased predicted survival and QALY gains, as well as cost savings and INMB, associated with further reductions in ARI risk in the countries we considered.

Our analysis emphasizes the potential impact in Canada of reductions in TB disease and infection in several key source countries for migration, rather than modelling the benefits and costs of specific approaches. Other groups have evaluated the impact and cost-effectiveness of such diverse interventions as novel TB vaccines, new point-of-care diagnostics for TB disease, active case-finding, and expanded use of TPT in these and other countries.^{51, 55-58} All potentially offer substantial health

gains in settings where TB incidence remains elevated and may represent cost-effective investments by Canadian and other governments, when both local and global health gains are considered. Further modelling work will help set priorities for specific interventions and investments accordingly.

Declarations

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Figures

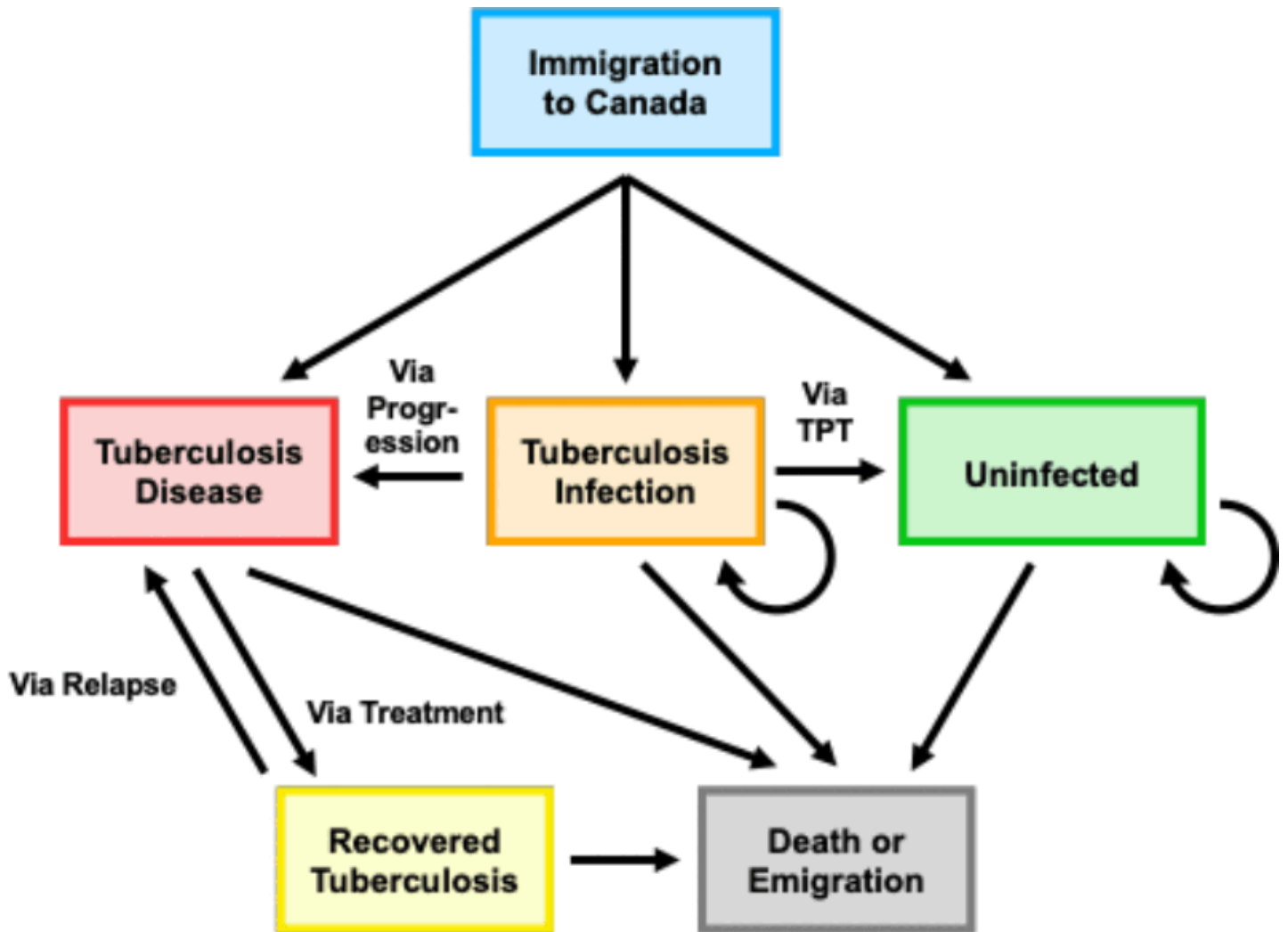


Figure 1

Simplified transition state diagram of Markov model. An open-cohort Markov decision analysis model was used to simulate TB epidemiology among foreign-born Canadians between 2001 and 2050. Individuals entered the model upon immigration to Canada and exited upon death or emigration. While in the model, individuals move between mutually exclusive health states, indicated by different coloured boxes. A more complex schematic of the Markov model used is available in Figure A2).

Predicted Probability of Tuberculosis Infection Upon Arrival in Canada Among Foreign-Born Individuals by Country of Origin

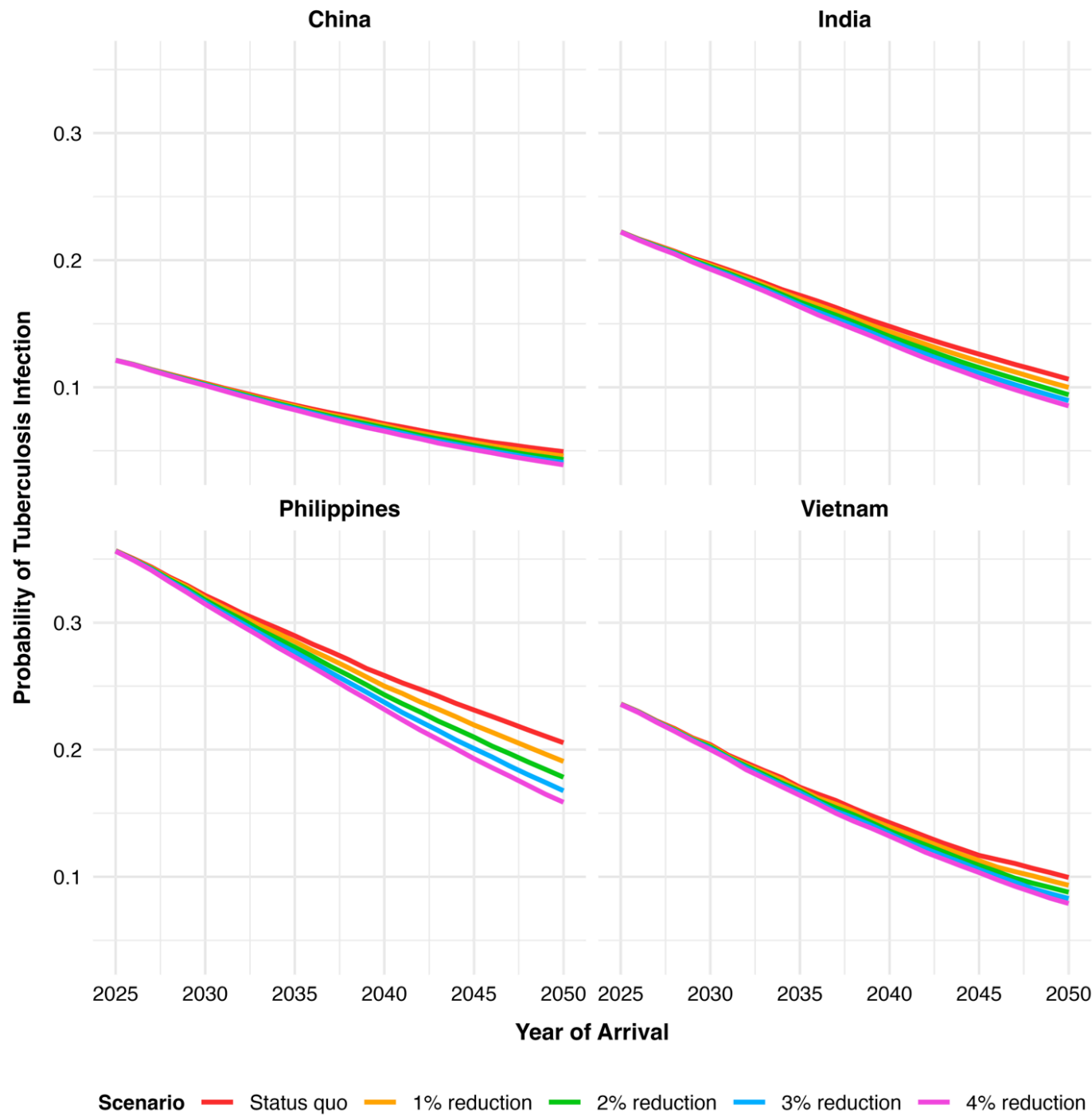


Figure 2

Estimated probability of tuberculosis infection upon arrival in Canada among foreign born individuals by country of origin, 2025-2050. Caption: The average decline in annual TBI risk was calculated between 2001 and 2021 for foreign-born individuals from China, India, the Philippines, and Vietnam and applied until year 2025. After year 2025, additional average reductions of 1%, 2%, 3%, and 4% per year were applied on top of the average annual decline in each country and extended until 2050. The probability of

TBI upon arrival to Canada is shown by country and indicated by colour. The URs have been excluded from the figure for ease of readability. The same figure with URs can be found in Appendix I, Figure A3.

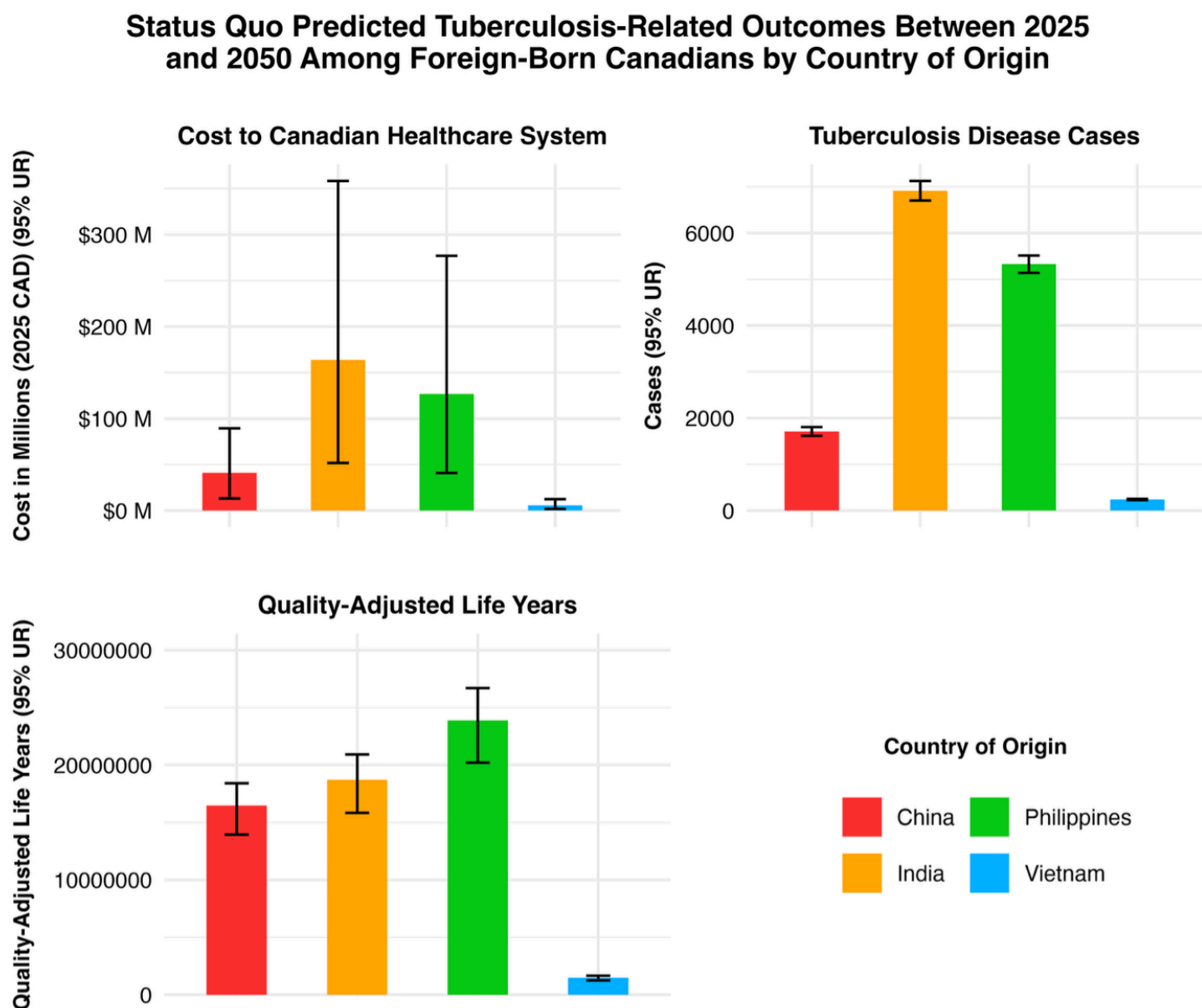


Figure 3

Status quo predicted tuberculosis-related outcomes between 2025 and 2050 among foreign-born Canadians from country of origin. Caption: TB-related outcomes (TB-related costs, TB disease cases, and QALYs) were predicted under the status quo scenario between 2025 and 2050 for foreign-born individuals from China, India, the Philippines, and Vietnam. The various countries of origin are depicted by colour, with 95% URs indicated by the black error bars.

Incremental Net Monetary Benefit Between 2025 and 2050 Among Foreign-born Canadians by Country of Origin

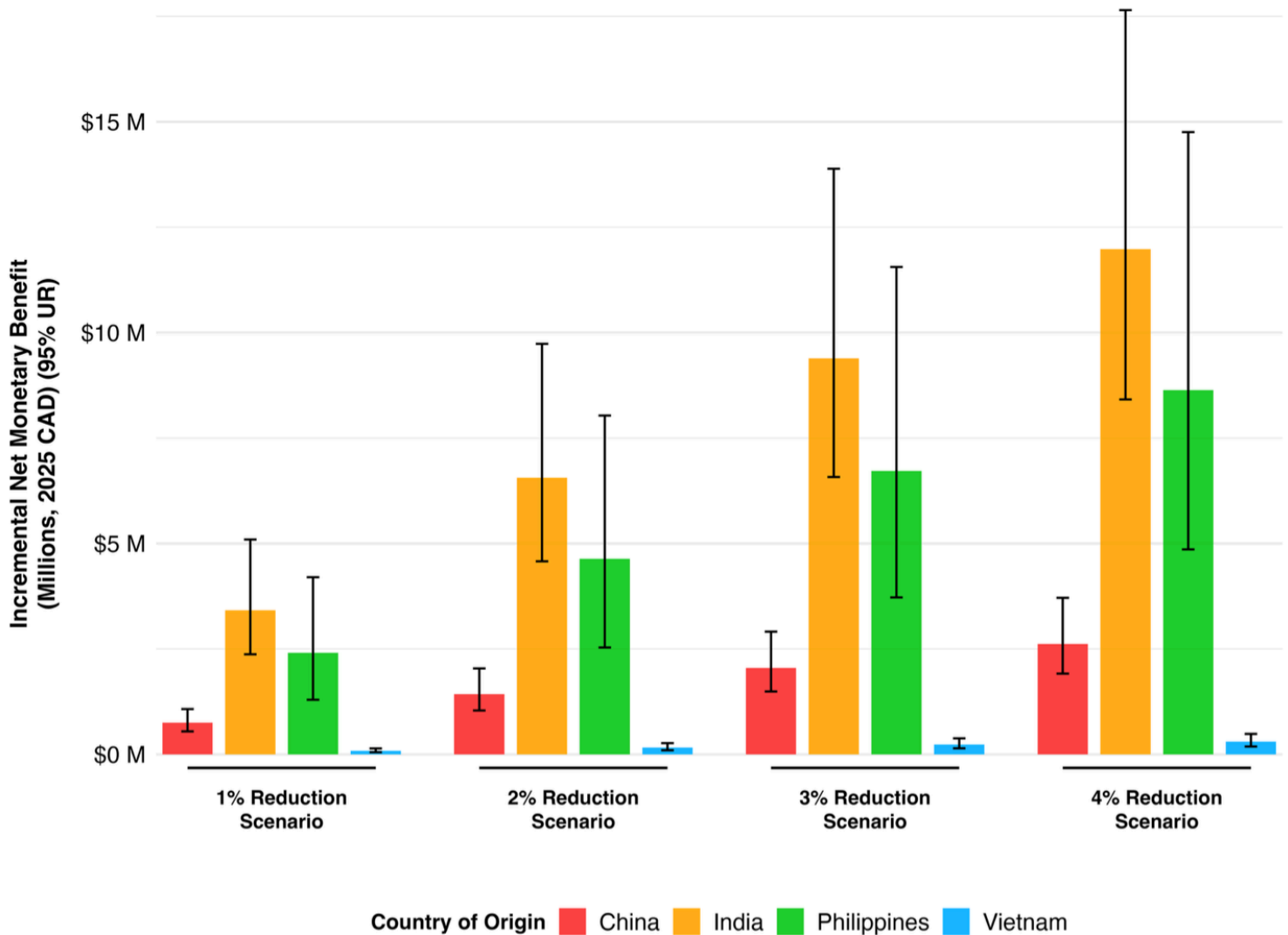


Figure 4

Incremental net monetary benefit between 2025 and 2050 among foreign-born Canadians by country of origin. Caption: The INMB between 2025 and 2050 was calculated for people born outside of Canada from China, India, the Philippines, and Vietnam. This was done using the predicted incremental costs averted and a WTP threshold of \$100,000 per QALY gained. The four different countries are denoted by colour, with a 95% UR shown with error bars. The largest incremental net monetary benefit in each scenario was predicted among individuals from India, followed by those from the Philippines, Vietnam, and China. The same figure normalized per 100,000 individuals is available in the appendix (**Figure A5**)

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [LKAppendixSept25.docx](#)