MODELING POTENTIAL HEALTH GAINS AND HEALTH SYSTEM SAVINGS ASSOCIATED WITH VAPORIZED NICOTINE PRODUCTS IN CANADA

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BACKGROUND

- In Canada, tobacco smoking prevalence is 15% among the total population aged 15 years and over.
- Vaporized nicotine products (VNPs) may assist adult smokers in switching away from combustible cigarette smoking. Public health authorities, including the National Academies of Sciences, Engineering, and Medicine (NASEM), Public Health England (PHE), and academics (ex. Levy et al.) note that vaping is associated with 5% of the risk of smoking combustible cigarettes.
- In New Zealand, a team of researchers adapted the Burden of Disease Epidemiology, Equity, and Cost-Effectiveness model (BODE) to assess the health and cost impacts of legalizing the domestic sale of VNPs.
- The AppEco multi-state life-table model (AppEco model) builds upon the core elements of the New Zealand model and adapts it to the Canadian context.

OBJECTIVE

To model population-wide health and cost impacts of VNPs for Canadian adults from 20 to 99 years old in 2015 who are followed for 80 years in a cohort-based model.

METHODS

Structure of the AppEco model (see figure on the right)

The AppEco model tracks, cohort by cohort, the health and cost impacts associated with varied levels of VNP use, on the selected population as they age, using a 0% discount rate for costs.

Data Sources

- Main lifetable: Statistics Canada for demographics and all-cause mortality.
- Smoking-related (SR) diseases: epidemiologic parameters for disease-specific incidence, prevalence, remission and case-fatality rates, as well as direct and indirect health costs using data from Statistics Canada, the Public Health Agency of Canada (PHAC), and the Canadian Institute for Health Information (CIHI).
- Smoking/vaping prevalence, transition matrices, and relative risks of SR diseases: Canadian Tobacco, Alcohol and Drugs Survey (CTADS), as well as existing epidemiological literature to supplement these rates.

Study Population

- Selected based on the number of Canadian adults aged between 20 and 99 years old in 2015 (n = 27,816,114).
- Rate and cost inputs divided into 68 cohorts separated by age (5-year age groups from 20-24 to 94-99 years old), sex, and ethnicity (Indigenous and non-Indigenous).

Smoking/Vaping Prevalence

For each scenario analyzed, the prevalence of smoking and vaping was modeled from 2015-2095 according to the following smoking/vaping state definitions based on 2015 questions/definitions of the Canadian Tobacco, Alcohol and Drugs Survey (CTADS).

- Current Smoker and Not Current Vaper (CSNV)
- Dual User (DU)
- Never Smoker and Not Current Vaper (NSNV)
- Former Smoker and Current Vaper (FSCV)
- Former Smoker and Not Current Vaper (FSNV)
- Never Smoker and Current Vaper (NSCV)

Smoking/Vaping State Transitions

- Each year, individuals in the AppEco model can either remain in their current smoking/vaping state, or transition to another state.
- Transition probabilities were estimated based on the work of Holford et al., Zhu et al., Coleman et al., and Manzoli et al., and applied using an approach similar to the BODE model.

Relative Risk

Using estimates of the NASEM, where RR_S = relative risk of disease for current vs non-smokers, and RR_F = relative risk of disease for former vs non-smokers, the relative harm associated with each state was estimated as follows:

- CSNV = RRS
- DU = 1 + 95%*(RRS - 1); 95 % of incremental risk of CS vs NS
- FSCV = RRF + 5%*(RRS - 1); FS vs NS risk plus 5 % of incremental risk of CS vs NS
- NSCV = 1 + 5%*(RRS - 1); 5 % of incremental risk of CS vs NS
- FSNV = RRF
- NSNV = 1; as there is no incremental risk of disease

Scenario Analysis

Three scenarios were projected and compared:

- The Status Quo scenario ("SQ") assumed the current situation in Canada, namely that VNPs are commercialized and regulated just as they are currently.
- The No-Vaping scenario ("NV"), a hypothetical scenario that assumed that VNPs never entered the Canadian market.
- The Policy Experiment scenario ("PE"), a projected test that modeled an increase in Canadian VNP prevalence in adult smokers that could result from changes in the regulatory or policy environment.

Differences in initial smoking/vaping prevalence rates drive the differences in disease incidence, mortality, remission, new prevalence, and associated costs between each scenario.

Measured Outcomes

- Life-years lost before the end of 85th year due to SR diseases, e.g., if a woman dies at 30 years old, her loss in life-years will be valued at 56 years.
- Total incremental social cost associated with each year of life lost, valued at approximately C$40,000 per individual per year lived.
- Cumulative disease costs over simulation timeframe.
- Cumulative mortality costs over simulation timeframe.

Sensitivity Analysis and Parameter Uncertainty

Sensitivity analyses included:

- Varying the 5% RR of vaping vs smoking to 10% and 25% and 50%.
- Varying the 95% RR of dual use vs smoking to 100%.
- Varying the 95% RR of dual use vs smoking to 70%.

Parameter Uncertainty:

- The model ran Monte Carlo simulations (n= 1,000) for baseline risk ratios for the cohort of non-Indigenous men aged 30-34 years old – chosen specifically because (a) it has high incremental costs for both scenario pairs and (b) a long modeling horizon (70 years).
- Published RRs included lower and upper bounds of confidence intervals, which allowed to approximate their distribution using log–normal distributions.
- Assuming fewer parameters to be uncertain increases the interpretability of the results and requires less ad hoc assumptions.

STRUCTURE OF THE APPECO MODEL

Data sources → **Main life-table**

Demographics and disease
Demographics
All-cause mortality
Disease incidence, prevalence and death rates
Health system and mortality costs

Smoking/vaping prevalence by state
Baseline prevalence rates
Transition matrices
Projected prevalences by scenario

Risk ratios of disease incidence by state
Baseline risk ratios by state, cohort and disease
Hoogenven adjustment
Statistical inference for Monte-Carlo simulations

Monte Carlo Simulation No	1								
Cohort ID	M20-24NI (=men, 20-24 years-old in 2015, non-Indigenous)								
Scenario	SQ			NV			PE		
Year	2015	2016	...	2015	2016	...	2015	2016	...
Cohort population	n	n	n	n	n	n	n	n	n
State-cohort prevalences: CSNV, DU, ..., NSNV	%	%	%	%	%	%	%	%	%
RR of disease incidence, by disease, year and scenario	$RR_{D, Y, Sc}$	$RR_{D, Y, Sc}$	$RR_{D, Y, Sc}$	$RR_{D, Y, Sc}$	$RR_{D, Y, Sc}$	$RR_{D, Y, Sc}$	$RR_{D, Y, Sc}$	$RR_{D, Y, Sc}$	$RR_{D, Y, Sc}$
Disease prevalence, beginning of year, cases	n_{PREV}	n_{PREV}	n_{PREV}	n_{PREV}	n_{PREV}	n_{PREV}	n_{PREV}	n_{PREV}	n_{PREV}
+ Disease incidence	n_{INC}	n_{INC}	n_{INC}	n_{INC}	n_{INC}	n_{INC}	n_{INC}	n_{INC}	n_{INC}
- Deaths due to smoking-related disease	n_{D}	n_{D}	n_{D}	n_{D}	n_{D}	n_{D}	n_{D}	n_{D}	n_{D}
- Disease remission	n_{R}	n_{R}	n_{R}	n_{R}	n_{R}	n_{R}	n_{R}	n_{R}	n_{R}
= Disease prevalence, end of year	n_{END}	n_{END}	n_{END}	n_{END}	n_{END}	n_{END}	n_{END}	n_{END}	n_{END}
N deaths									
Due to smoking-related diseases	n_{SD}	n_{SD}	n_{SD}	n_{SD}	n_{SD}	n_{SD}	n_{SD}	n_{SD}	n_{SD}
From all other causes	n_{OTHER}	n_{OTHER}	n_{OTHER}	n_{OTHER}	n_{OTHER}	n_{OTHER}	n_{OTHER}	n_{OTHER}	n_{OTHER}
Life-years lost due to SR diseases	LYL_{SD}	LYL_{SD}	LYL_{SD}	LYL_{SD}	LYL_{SD}	LYL_{SD}	LYL_{SD}	LYL_{SD}	LYL_{SD}
Cost outcomes SR diseases and mortality									
Health system costs	$\$_{HS}$	$\$_{HS}$	$\$_{HS}$	$\$_{HS}$	$\$_{HS}$	$\$_{HS}$	$\$_{HS}$	$\$_{HS}$	$\$_{HS}$
Mortality (productivity) costs	$\$_{MP}$	$\$_{MP}$	$\$_{MP}$	$\$_{MP}$	$\$_{MP}$	$\$_{MP}$	$\$_{MP}$	$\$_{MP}$	$\$_{MP}$
Cumulative cost outcomes	$\$_{CUMUL}$	$\$_{CUMUL}$	$\$_{CUMUL}$	$\$_{CUMUL}$	$\$_{CUMUL}$	$\$_{CUMUL}$	$\$_{CUMUL}$	$\$_{CUMUL}$	$\$_{CUMUL}$

Other characteristics
Cohorts are simulated one at a time: sex (men, women), ethnicity (non-Indigenous and Indigenous), and age (20-24, 25-29, ..., 95-99).
The main life-table depicted above is for simulation 1, performed at mean values for all inputs. For Monte-Carlo simulations, the model has been "stacked" on a single column, and replicated to generate the 1,000 simulations.
Although this study presents results for all of Canada, the AppEco model is built to simulate outcomes for any combination of province(s) and territorie(s).

INITIAL RESULTS

Life years lost due to smoking-related (SR) diseases; incremental social cost (value) of life years lost, and cumulative total health and productivity costs (value)

- Compared to the NV scenario, the SQ scenario would have lowered projected life-years lost due to SR diseases by 1.8%, and avoided a projected C$39.0 billion in social cost of life years lost, and in health and mortality costs.
- Compared to the SQ scenario, In the PE test, life-years lost due to SR diseases decreased by 1.4% and a total of C$30.4 billion in social cost of life-years lost, and total health and mortality costs were saved. This suggests even further incremental benefit in the PE test as compared to the NV scenario.

	SQ - NV		SQ - PE	
	Var.	%	Var.	%
Life years lost due to SR diseases	-922,547	-1.8%	718,137	1.4%
Social cost of life years lost due to SR diseases	36,901,884,999 $	--	-28,725,482,105 $	--
Cumulative total health and mortality (productivity) costs	2,124,200,547 $	1.2%	-1,667,407,670 $	-0.9%
Cumulative disease costs	2,073,664,117 $	1.2%	-1,613,294,031 $	-0.9%
Cumulative mortality (productivity) costs	50,536,431 $	1.0%	-54,113,639 $	-1.0%
Incremental cost (value) of SQ scenario	**39,026,085,547 $**		**-30,392,889,775 $**	

Total incremental costs (value), by sex and ethnicity

- Younger cohorts of men are projected to gain incrementally more benefits in terms of life-years gained and avoided costs associated with SQ, as compared to the NV scenario.
- In the PE test, higher projected savings and life-years gained were observed in Canadian cohorts with higher prevalence of VNP use, as compared to the existing SQ scenario.

Life years lost due to SR diseases; incremental social cost (value) of life years lost, and cumulative total health and productivity costs (value) by sex and ethnicity

	Life years lost due to SR diseases		Social cost (value) of life years lost due to SR diseases		Cumulative total health and mortality (productivity) costs (value)	
	SQ vs. NV	SQ vs. PE	SQ vs. NV	SQ vs. PE	SQ vs. NV	SQ vs. PE
Values						
Total	**-922,547**	**718,137**	**36,901,884,999 $**	**-28,725,482,105 $**	**2,124,200,547 $**	**-1,667,407,670 $**
Men	-585,890	495,198	23,435,604,268 $	-19,807,907,935 $	1,446,374,830 $	-1,213,509,232 $
Non-Indigeneous	-569,097	470,114	22,763,892,196 $	-18,804,559,536 $	1,412,447,605 $	-1,164,397,115 $
Indigeneous	-16,793	25,084	671,712,072 $	-1,003,348,399 $	33,927,226 $	-49,112,117 $
Women	-336,657	222,939	13,466,280,732 $	-8,917,574,170 $	677,825,717 $	-453,898,437 $
Non-Indigeneous	-325,877	208,220	13,035,076,331 $	-8,328,789,200 $	659,713,502 $	-429,949,322 $
Indigeneous	-10,780	14,720	431,204,401 $	-588,784,970 $	18,112,215 $	-23,949,116 $
Percent difference						
Total	-1.8%	1.4%	--	--	-1.2%	0.9%
Men	-1.9%	1.6%	--	--	-1.3%	1.1%
Non-Indigeneous	-1.9%	1.6%	--	--	-1.3%	1.0%
Indigeneous	-1.4%	2.0%	--	--	-1.0%	1.4%
Women	-1.7%	1.1%	--	--	-1.1%	0.7%
Non-Indigeneous	-1.7%	1.1%	--	--	-1.1%	0.7%
Indigeneous	-1.3%	1.8%	--	--	-0.8%	1.1%

Sensitivity analysis for life-years lost due to SR diseases

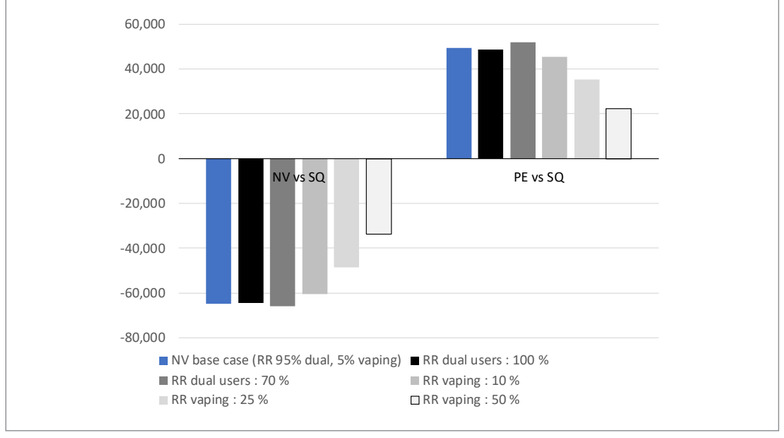
- When varying the relative risk of vaping vs. smoking, results consistent with our baseline inputs were noted, both in life-years lost or gained (see figure below), and in incremental direct and indirect health costs.

Monte Carlo simulations (N = 1,000) for cohort of non-Indigenous men aged 30-34 in 2015

- Every projected result of both scenarios using the mean value of inputs was nearly identical to the mean of 1,000 simulations, confirming that even for cohorts with large cost values and a long projection horizon, the model's projections are stable and statistically significant across all projected outcomes.

Scenario comparison	Results using mean values for all inputs	Monte Carlo simulations (N=1,000)		
		Mean	95% confidence interval	
			Lower bound	Upper bound
SQ - NV				
Life years lost due to SR diseases	-64,792	-64,571	-82,993	-48,280
Social cost of life years lost due to SR diseases	2,591,666,083 $	2,582,826,680 $	3,319,708,881 $	1,931,200,401 $
Cumulative total health and mortality (productivity) costs	156,773,939 $	156,085,679 $	205,035,287 $	113,950,036 $
Cumulative disease costs	150,902,408 $	150,231,717 $	197,157,920 $	109,770,965 $
Cumulative mortality (productivity) costs	5,871,531 $	5,853,962 $	7,877,367 $	4,179,071 $
Incremental cost (value) of SQ vs. NV scenario	**2,748,440,021 $**	**2,738,912,359 $**	**3,524,744,168 $**	**2,045,150,437 $**
SQ - PE				
Life years lost due to SR diseases	49,332	49,171	36,659	63,370
Social cost of life years lost due to SR diseases	-1,973,267,861 $	-1,966,835,557 $	-1,466,375,589 $	-2,534,787,791 $
Cumulative total health and mortality (productivity) costs	-134,052,558 $	-133,517,678 $	-95,446,974 $	-178,903,567 $
Cumulative disease costs	-126,431,621 $	-125,919,641 $	-90,064,844 $	-168,624,480 $
Cumulative mortality (productivity) costs	-7,620,937 $	-7,598,037 $	-5,382,130 $	-10,279,087 $
Incremental cost (value) of SQ vs. UK scenario	**-2,107,320,419 $**	**-2,100,353,235 $**	**-1,561,822,563 $**	**-2,713,691,358 $**

SENSITIVITY ANALYSIS - *Life years lost du to SR diseases*



LIMITATIONS

- Smoking and vaping prevalence rates, which were based on the six Statistics Canada definitions of smoking/vaping states, do not account for use frequency, and are held constant over time.
- CTADS does not cover the Yukon, Northwest Territories and Nunavut.
- The uncertainty surrounding parameter estimates for small samples can become too large to get conclusive results. Therefore, scenario analysis was used to project results for each cohort, including smaller ones, rather than simulations (e.g., Monte-Carlo, bootstrap, etc.).

CONCLUSIONS

- Scenarios with higher levels of vaping prevalence were observed to reduce the total amount of life-years lost, diminish the costs associated with SR disease and mortality, and increase the total incremental social value at the population level, as compared to a scenario where VNPs are not available.
- Increased uptake of VNPs in Canada may generate net public-health gains and health-system cost savings.
- Projected health and economic consequences are sensitive to assumptions about accessibility and use by adult smokers, and may vary by type of policy environment.

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