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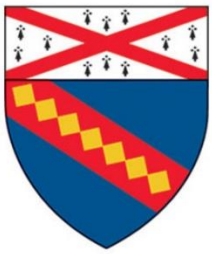

MODELING THE POLICY IMPACT ON THE DYNAMICS OF TOBACCO PRODUCT USE

BY

Tianzhou Yu

A thesis submitted in partial fulfilment of the requirements for the degree of

Master of Public Health

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Abstract

Objective

Smoking is the leading cause of preventable death. While the proportion of the U.S. population that uses combustible tobacco products has been declining over the past decade, use of e-cigarettes among youth and young adults has risen. Our objective was to model the prevalence of tobacco product use in 10 years given the current policy environment and project product use patterns if new policies are adopted.

Methods

Using data from the literature, we constructed a microsimulation model for the period 2015 – 2025 with the following Markov states: combustible use only, e-cigarette use only, dual use, former use, never use, and death. We projected the tobacco product use prevalence in 2025 and assessed the policy impact by comparing the difference in projections.

Findings

We found that in the current policy environment, the proportion of individuals who do not use tobacco will increase by 5.5 percentage points by 2025, while prevalence of combustible products, e-cigarette, and dual use will decrease by 4.5, 1.1, and 1.3 percentage points, respectively. An implementation of youth restriction to flavored electronic nicotine delivery system (ENDS) products would not result in any changes in the projected tobacco product use pattern in 2025. A menthol ban would lead to a 3.2 percentage points increase in the prevalence of non-users and a 2.9 percentage points decrease in combustible use without any substantial change to the e-cigarette use prevalence.

Conclusions

In the current policy environment, smoking prevalence will continue to drop, as it did over the past decade. A policy restricting youth access to flavored ENDS products will not have any effect on the projected 2025 tobacco product use patterns on its own. On the other hand, a menthol ban would encourage people to quit tobacco use and accelerate the current trend of declining smoking prevalence.

Keywords: tobacco use, microsimulation, e-cigarette, menthol, youth access, chronic disease epidemiology

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Introduction

Smoking is the leading cause of preventable death, costing smokers approximately 10 years of life. [1] Smoking also costs the United States nearly $170 billion in direct medical care for adults and more than $156 billion in lost productivity.[2,3] However, in 2016, 15.5% of all adults (37.8 million people) still reported cigarette smoking.[4] More alarmingly, each day more than 3,200 people younger than 18 smoke their first cigarette and an estimated 2,100 young occasional smokers become daily cigarette smokers.[2]

Although cigarette smoking among U.S. adults has declined considerably, smoking is still responsible for over 480,000 deaths per year in the United States.[5] In addition, tobacco products have evolved in recent years to include various combustible, noncombustible, and electronic products. In 2017, an estimated 47.4 million U.S. adults (19.3%) currently used any tobacco product, including cigarettes (14.0%; 34.3 million); cigars, cigarillos, or filtered little cigars (3.8%; 9.3 million); electronic cigarettes (e-cigarettes) (2.8%; 6.9 million); smokeless tobacco (2.1%; 5.1 million); and pipes, water pipes, or hookahs (1.0%; 2.6 million).[6]

Electronic cigarettes, also known as Electronic Nicotine Delivery System (ENDS), were first introduced to the U.S. in 2007. Electronic cigarettes vary in design but generally contain a heating element which allows for inhalation of vaporized solution containing nicotine. Because electronic cigarettes are a relatively new product, little is known about the long-term health risks associated with use, although some compounds contained in e-cigarettes are known irritants. Nicotine itself has some associated risks including cardiovascular effects. However, in comparison, combustible tobacco releases thousands of harmful constituents into the body that result in known harmful effects.[7,8] E-cigarettes have been proposed as a product that may help

adult smokers transition off combustible tobacco to e cigarettes which presumably are products with a lower associated risk profile.[9] Electronic cigarettes also provides the flexibility of adjusting nicotine content in the product by users, which could ease the transition process from cigarette smoking to quitting.

However, e-cigarettes have several drawbacks. First, although e-cigarettes may be less harmful than combustible tobacco and may help users quit, some public health advocates have argued that users of combustible tobacco should not replace tobacco with a product with unknown long-term harms but instead should rely on cessation methods with known safety profiles. Second, public health officials have noted that e-cigarettes have become increasingly popular among youth. E-cigarette use among youth is problematic for two reasons: first, e-cigarettes expose a vulnerable population to high levels of nicotine, an extremely addictive substance. Second, e-cigarettes may act as a "gateway" to combustible tobacco. Thus, there is concern that the appeal of e-cigarettes to the young population could promote smoking and even dual use with other tobacco products, or even marijuana and illegal drugs.[10–12]

In a recent press release, the FDA announced that data from the 2018 National Youth Tobacco Survey revealed that there was a 78% increase in current e-cigarette use among high school students and a 48% increase among middle school students from 2017 to 2018. The total number of middle and high school students currently using e-cigarettes rose to 3.6 million, almost doubled from the previous year. [8] Increased use of e-cigarette among youth could promote their transition to combustible tobacco products after they become adults. Alarmed by those findings and equipped with a determination to stop the current trend, the FDA recently proposed several new policies related to tobacco products, including:

1. All flavored ENDS products are to be sold in age-restricted, in-person locations and, if sold online, under heightened practices for age verification.

2. Menthol will be banned in combustible tobacco products, including cigarettes and cigars.[8]

In 2009, passage of the U.S. Family Smoking Prevention and Tobacco Control Act led to a ban on the sale of flavored cigarettes, but the ban did not apply to menthol cigarettes or any tobacco products beside cigarettes. A study showed that, among adolescents, this regulatory action was associated with a reduction in the probability of being a cigarette smoker, but was also associated with increases in menthol cigarettes, cigar, and pipes use, indicating that some users were switching to the remaining legal flavored tobacco products at that time.[13] This suggests that restricting youth access to flavored ENDS products may have the potential to reduce adolescent and overall tobacco product use. However, past studies have also found that policies that restrict youth access to cigarette has not been effective as expected.[14–16] Therefore, the effect of the proposed age restriction to flavored ENDS products remains elusive.

Similarly, there is also uncertainty in the effect of a menthol ban on combustible products. According to a recent study in Ontario, Canada, 29.1% of the menthol cigarette smokers quitted or made an attempt to quit smoking one month after a full menthol cigarette ban and another 29.1% switched to alternative flavored products including e-cigarettes and cigars. [17] Compared with 14.5% intended to quit and 5.8% intended to use alternative flavored products, the menthol ban was more effective than expected. However, in the long run, only 17.0% of the smokers intended to stay away from any tobacco products and 2.9% planned to completely replace menthol cigarettes with alternative flavored products. The study suggested that a menthol

ban would be a promising strategy to reduce combustible product use but its impact is not clear based on the limited observational data.

The objective of this study is to use a microsimulation model to project the dynamics of tobacco product use over the next 10 years in the United States, including combustible tobacco use, e-cigarettes use, and dual use among adults. Our model will take into account the current policy environment and project the possible effects of the proposed FDA policies. The impact of the proposed policy is measured by comparing the difference of the prevalence of tobacco product use 10 years from 2015 in the current policy environment (the base model) and the model under the proposed policies. We also use this model to identify and explore uncertainties related to this policy.

Research Design

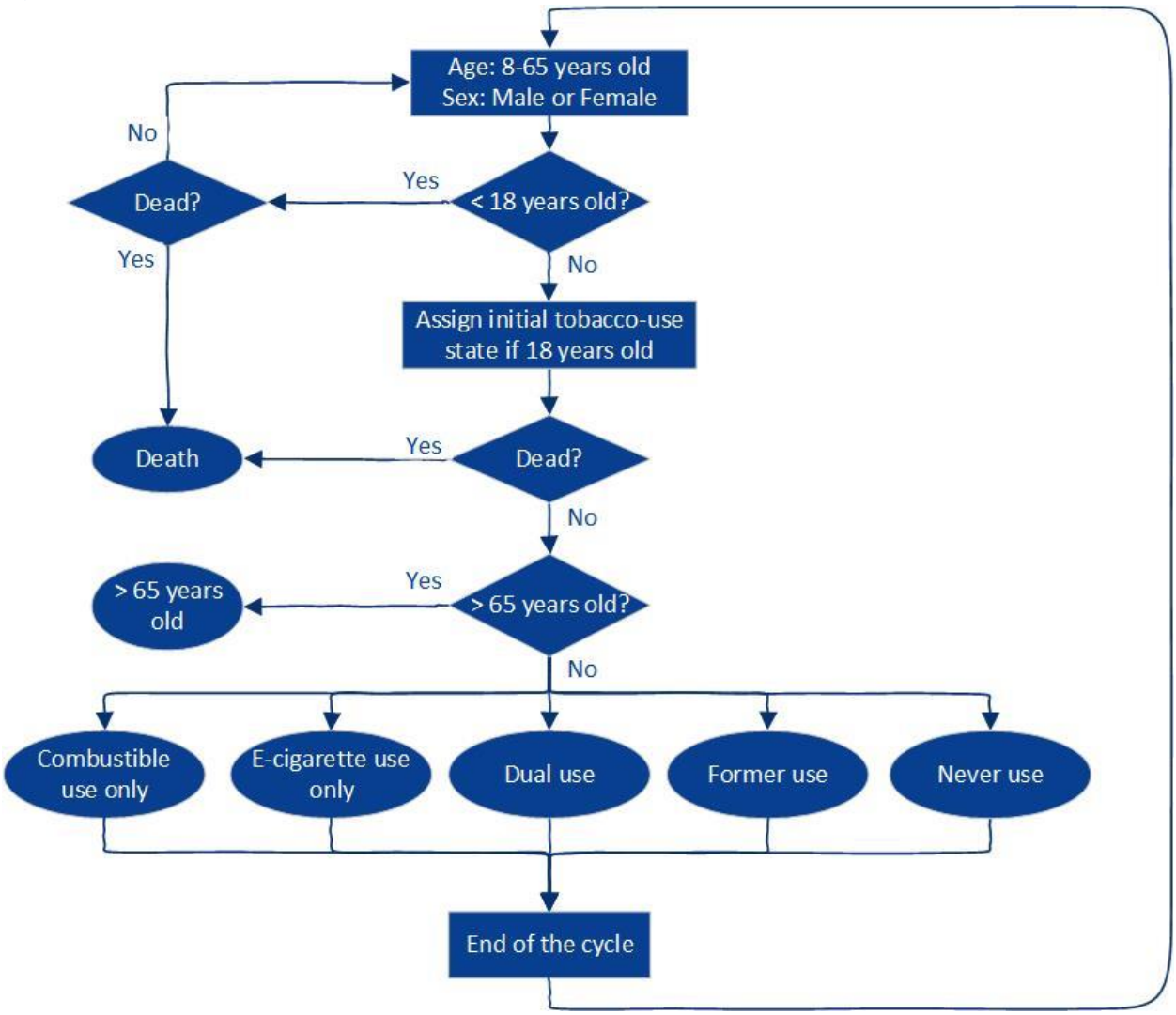
Model Overview

We developed a microsimulation model that projects the potential impacts of proposed tobacco policies on tobacco use patterns among adults in the U.S. Compared to cohort models, the microsimulation model provides the flexibility of incorporating transition probabilities and distributions specific to sex, age, and year.

This model simulated a population of U.S. adults, aged 18 to 65, and their respective tobacco product use from 2015 to 2025. The model has five tobacco-product-use states ("combustible use only", "e-cigarette use only", "dual use", "never use", and "former use"), two absorbing states ("older than 65 years old" and "death"), and one additional state ("younger than 18 years old") which allows the modeled population to "age" into and out of the model. (**Figure 1**) All states are mutually exclusive from each other.

The model was built in TreeAge Pro 2019 (TreeAge Software, Inc., Williamstown, MA, USA). All linear regressions and extrapolation of the projected future was done in R Studio (R Studio, Boston, MA, USA). Outcome analysis was done in Excel 2016 (Microsoft, Redmond, Washington, USA). Consistent with our data sources, we defined current smoking as having smoked at least 100 cigarettes in one's lifetime and currently smoking every day or some days. We defined current e-cigarette use in this model as any individual using e-cigarettes every day or some days.

Figure 1. Model overview



Model Description

Each simulated individual has an assigned sex and age when first entering the model. All individuals age by one year after completing one cycle in the model. If an individual is older than or equal to 18 years old, the individual will be assigned an initial tobacco-product-use state based on the predicted tobacco-product-use distribution of the year when the individual enters the model.

At each time step, every simulated adult either lives through the whole year or dies by the end of that year. The probability of death depends on age and sex, based on the 2015 mortality rates as reported by the Centers for Disease Control and Prevention (CDC).[18] Individuals who survive but will turn 66 in the next cycle age out of the model. In both cases, the individual leaves the model and will not be counted in the remaining years. Conditional on living through the year and not aging past 65, the individual then either stays in the current tobacco-product use state or moves to a different state at the beginning of the next cycle. Transitions among the tobacco-product use states were probabilistic and determined by a combination of: age, sex, year, and the individual's current state. Each individual stays in the model for 10 cycles unless the individual dies before reaching the 10^{th} cycle.

To capture youth who will become adults over the modeled 10-year period, the model included simulated individuals younger than age 18. These individuals could age into the model when they turn 18 or die before the age of 18. If they age into the model, they are assigned a tobacco product use state based on age, year, and sex.

Model Assumptions

The probability of moving to a different state in the model (i.e. the transition probability) is based only on the individual's current state, age, sex, and year, but not the individual's past smoking history in the model (the states the individual has visited).

Smoking initiation (from never use to combustible use only) and cessation (from combustible use only to former use) probabilities have been reported to be decreasing and increasing, respectively, in a linear fashion from 2005 to 2015.[19] (**Figure A1**) Therefore, using these reported transition probabilities from 2005 to 2015, we performed age-and-sex-specific linear regressions by year to extrapolate the initiation and cessation probabilities of an individual with certain sex and age attributes in each year from 2015 to 2025, assuming that these probabilities will continue to change following the same trend. (**Table A1**) Because initial smoking cessation efforts within 2 years are often not successful, the study only classified people who have quit smoking for more than two years as former smokers, leading to lower reported cessation probabilities. Thus, to incorporate the change in cessation probabilities by year and to approximate the cessation probabilities within one year, we multiplied the predicted cessation probabilities from the regression by an inflation factor (9 for 18-24-year-olds; 4 for 25+).

Among no users (never users + former users), there is a reported increase of proportion of never users from 2010 to 2013. [20] We assumed the increase to be a linear function of year and conducted a linear extrapolation to predict the projected ratio between never users and former users among non-users. (**Figure A2**) In addition, prevalence of tobacco product use of the 18-year-olds entering the model at the beginning of each cycle was allowed to change linearly by year. Specifically, for the individuals who had just aged into the model, they were less likely to

be combustible product users or dual users, more likely to be e-cigarette users or never users, and as likely to be former smokers. [6,21,22] The specific amount of change each year was determined by the linear regression equation conducted based on the 2013-2017 data. (**Table A2**)

In the US population, the number of people from 10 to 64 is nearly uniformly distributed across this age group in 2015.[23] (**Figure A3**) Therefore, we assigned the age to each simulated individual based on a uniform distribution, ranging from 8 to 65. The sex of the simulated individuals was also based on a uniform distribution between 0 and 1, with 0 representing male and 1 representing female.

Model Parameters

Current policy environment

We used data from the existing literature, primarily studies using the Population Assessment of Tobacco and Health (PATH) Study data to inform this model. The PATH Study is a nationally representative longitudinal study of tobacco use in the United States.[24] Importantly, because the PATH study follows individuals over time, it provides information on the probability of tobacco product initiation, switching, and cessation over time. The PATH study also allows for quantifying tobacco product use and transitions by age group (18-24 and 25+) and by sex. To capture the changing patterns of combustible tobacco product use, we incorporated National Health Interview Survey (NHIS) data on annual smoking initiation and cessation probabilities by age, sex, and calendar year to vary these transition probabilities in the model. Data from the PATH and NHIS informed the base case—i.e., the current policy environment. (**Table 1**) In

Table 1. Transition probability matrix by age group in the current policy environment.

	Combustible only	E-cigarette only	Dual use	Former use	Never use
18-24 years old					
Combustible only	#	0.022	0.176	*	0
E-cigarette only	0.212	#	0.215	0.265	0
Dual use	0.371	0.059	#	0.122	0
Former use	0.091	0.022	0.029	#	0
Never use	*	0.023	0.009	0	#
25+ years old					
Combustible only	#	0.014	0.106	*	0
E-cigarette only	0.135	#	0.147	0.205	0
Dual use	0.433	0.058	#	0.074	0
Former use	0.040	0.005	0.003	#	0
Never use	*	0.002	0.0005	0	#

 # Complement of the row
** Calculated based on age, sex, and year for each simulated individual in the model at each time step*

addition, to make the model more representative of the real-world use patterns, we also allowed the tobacco product use prevalence to change for the entering 18-year-olds during each cycle of simulation, as predicted by a regression based on reported prevalence from 2013 to 2017.[6,21,22,25]

Age restriction to flavored ENDS products

According to a recent study, the ban on flavored cigarettes was associated with a 17% reduction in the probability of being a smoker among adolescents.[13] We assumed that the same amount of reduction in e-cigarette users would be observed among adolescents if a ban on flavored e-cigarettes takes place. Therefore, we projected the impact of the age-restriction of flavored ENDS product sales by adjusting the percentage of exclusive e-cigarette use population of the 18-year-olds at the beginning of each cycle. Specifically, compared to the predicted tobacco use pattern each year in the base case, the predicted proportion of population that only uses e-cigarette at that year was reduced by 17%. Since the study did not differentiate never use and former use, we reclassified the tobacco use state of those 17% of exclusive e-cigarette use population in the base case as never use. (**Table A3**)

Menthol ban

The impact of the menthol ban in combustible products was projected by incorporating information from prior studies of tobacco policies. Specifically, according to a recent study in Ontario, Canada, 17.0% of menthol smokers intended to quit and 2.9% planned to switch to alternative flavored products in response to a menthol ban.[17] Based on this study, we assumed that all of the menthol smokers who intended to quit in the long run will quit successfully in a year and those who planned to switch to alternative flavored products all switched to exclusive e-cigarette use in a year. Noting that menthol cigarettes comprise 5% of cigarette sales in Canada

compared with 25% in the United States, we calculated that 25% * 17.0% = 4.25% of current combustible product users will quit tobacco use and 25% * 2.9% = 0.725% of current combustible product users will switch to e-cigarette use.[17,26] We adjusted the transition probabilities in our model accordingly to project how this policy might similarly impact tobacco use behaviors in the US. (**Table A4**)

Model Calibration

We calibrated this model using the data from *Tobacco Product Use Among Adults* series of report from 2013 – 2014 to 2017 so that the model accurately captures the changing patterns of tobacco product use in the US. The report series contain data of tobacco product use in 2013 – 2014, 2015, and 2017 on "any combustible tobacco product", "e-cigarette use", and "any tobacco product" for three age groups (18-24, 25-44, and 45-64). The transition probabilities for 25+ years old apply to both the 25-44 and 45-64 age groups.

We approximated the prevalence of dual use from the reported percentage of "> 2 products use", which is included in the 2015 and 2017 report but not in the 2013 – 2014 report. Previous studies have reported that approximately 32.5% of any tobacco product users were multiple product users in 2012.[27,28] Based on this estimate, we assumed that in the 2013 – 2014 report, there were approximately 28% of the any tobacco use population that also belonged to the "> 2 products use" category.

We assumed that the 2013-2014 report represent the tobacco product use pattern in the 2014 calendar year and there are consistently 30% of multiple product users among all tobacco product users from 2014 to 2017, as shown in the 2017 report. Because the categories in the

reports are not mutually exclusive (e.g. a cigarette and e-cigarette dual user would be counted in "> 2 products use", "any combustible tobacco product", and "e-cigarette use"), we subtracted 30% of the "> 2 products use" from the "e-cigarette use only" population to account for double counting. Similarly, we estimated that 90% of the dual users were using at least one combustible product and were therefore removed from the "combustible use only" population in our model.[29]

The number of non-users was calculated as the complement of the reported percentage of "any tobacco product use". The proportion of never use and former use among non-users for each year was determined by a predicted ratio based on observed data from 2010 - 2013.

The model was validated by comparing the actual tobacco product use prevalence and the simulated results in 2014 and 2017. (**Table A5**)

Sensitivity Analysis

Since e-cigarettes are gaining in popularity, transition probabilities associated with e-cigarette or dual use may change in future years. Therefore, we performed one-way sensitivity analysis of some of the key transition probabilities and assumptions, including the proportion of combustible product users among dual users, the transition probability of switching from combustible tobacco to e-cigarettes, and the transition probability switching from e-cigarettes to combustible tobacco. This allowed us to evaluate the impact of the uncertainty in those key model parameters and policy assumptions.

According to data reported in the *Tobacco Product Use Among Adults — United States, 2017*, at least 75% of the dual use population uses at least one combustible product. [6] The PATH study reported 1.3% of non-combustible and e-cigarette dual users among all multiple product

users, which consists of 10.2% of the total sample, bringing the estimate to 13%.[29] As a result, this proportion was allowed to vary from 70% to 100%. (**Table 2**)

In addition, the role of e-cigarette as a gateway tobacco product or a cessation aid are still uncertain, and likewise, the associated transition probabilities in this model are uncertain. We varied the probability of switching from combustible tobacco to e-cigarettes and from e-cigarettes to combustible tobacco based on reported 95% confidence intervals. (**Table 2**)

Table 2. Range of values used in one-way sensitivity analysis.

	Lower bound	Upper bound
Proportion of any combustible user among dual users	0.7	1.0
Transition probability from combustible to e-cigarette use	0.0157 (18-24) 0.0115 (25+)	0.0294 (18-24) 0.0178 (25+)
Transition probability from combustible to dual use	0.1572 (18-24) 0.0974 (25+)	0.1960 (18-24) 0.1156 (25+)

Results

Current Policy Environment

The proportion of individuals who are not currently using any tobacco product (no use) was projected to continue rising as it has been over the past decade. The projected increase from 2015 to 2025 was mainly driven by the increase in the former use population (8.7 percentage points), which corresponded to the decline in the population that uses combustible tobacco products (4.8 percentage points). The population of adults who have never used any tobacco product (never use) declined, albeit by a very small amount, until 2022 and then plateaued. The e-cigarette use and dual use populations were projected to decrease by 1.1 and 1.3 percentage points, respectively. Those declines, while large on their own, did not contribute substantially to the overall change in the tobacco product use prevalence. (**Figure 2**)

By 2025, the projection showed that 14.6% of the total population will still use combustible products, 2.9% use e-cigarettes, 3.5% are dual users, and 83.2% do not use any tobacco products.

Age Restriction to Flavored ENDS Products

Restricting access to flavored ENDS products among youth appeared to have little impact of product use patterns among adults. (**Figure A4**) While there were some minor differences in the prediction of individual categories in some years between 2015 and 2025, the projected 2025 tobacco use pattern after implementing the age restriction on flavored ENDS products was the

Figure 2. Tobacco use pattern from 2015 to 2025 in the current policy environment

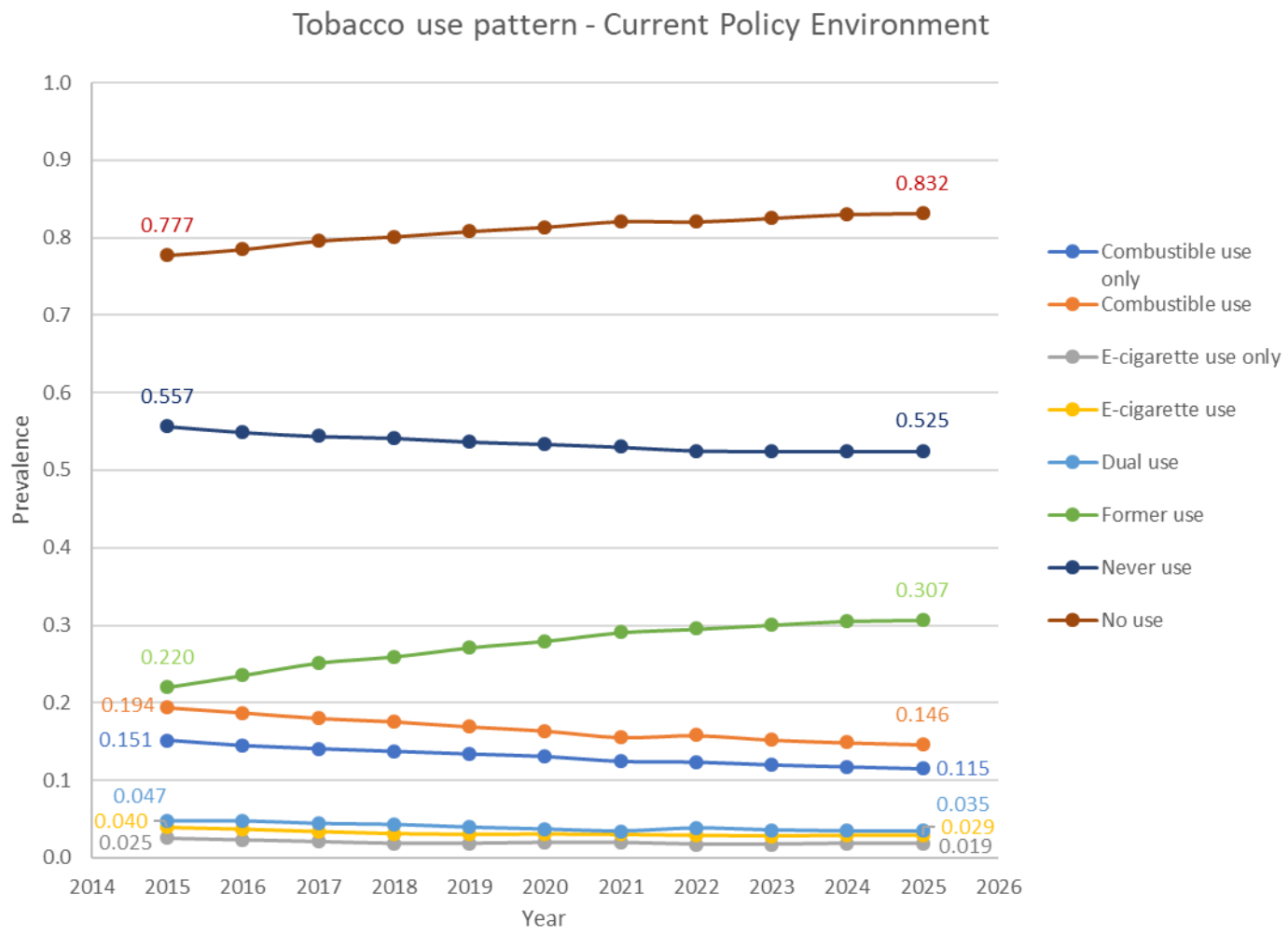
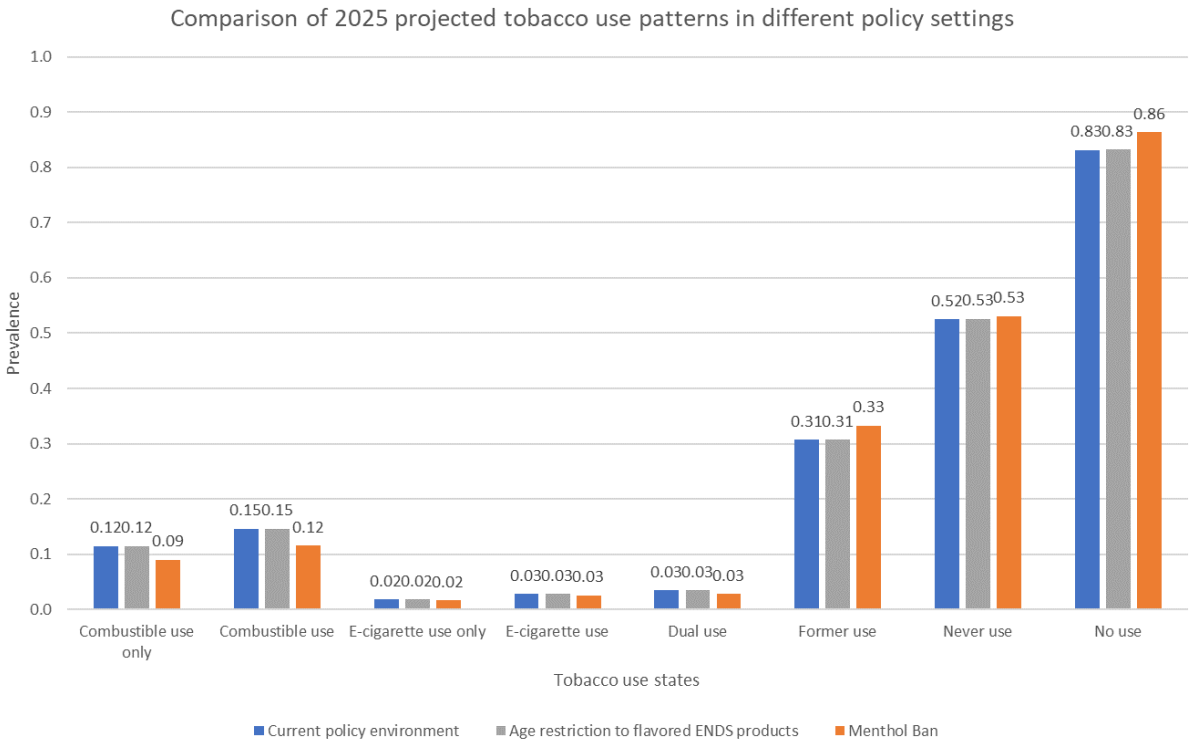


Figure 3. Comparison of tobacco use patterns in different policy settings from 2015 to 2025



same as in the current policy environment, except for a negligible 0.1 percentage point increase in the never use population. (**Figure 3**)

Menthol Ban

The projected outcome under menthol ban followed the same trend as in the base case. (**Figure A5**) There were slight decreases in e-cigarette use (2.9% vs 2.6%) and dual use (3.5% vs 2.8%) between current policy environment and if menthol ban is adopted. As expected, the population that used combustible products declined more (3.0 percentage points) with menthol ban than in the current policy environment. As a result, the "no use" population in 2025 was higher (3.2 percentage points) with a menthol ban than without, but the change mainly comes from the former use population. The change resulted from the policy in the never use population is minimal. (**Figure 3**)

Sensitivity Analysis

No substantial variation in the projected 2025 tobacco product use pattern was observed when varying the proportion of combustible product users among dual users. Similarly, we did not see substantial variation of the 2025 projection from varying the transition probabilities of switching from combustible use to e-cigarette use and from e-cigarette use to former use. (**Figure A6**)

Discussion

Current Policy Environment

The prevalence of smoking has been declining since the 1980s.[19] Our model projects that under the current policy environment, this trend will continue onward and we should expect the prevalence of combustible product use to keep dropping, along with an increase in the non-use population. We also see that in our model, the rate of change for the combustible use prevalence is leveling off over time and the model seems to be approaching a steady state.

Our model predicts that the never-use population will actually decline slightly until 2022. This reflects complex dynamics but may be in part because of the recent surge in the e-cigarette use among youth and young adults. Since the e-cigarettes have become more popular and readily available than before, a higher than expected percentage of never users started to become e-cigarette users. However, the population that uses e-cigarettes or co-uses more than one product are also decreasing. This suggests that while many are starting to use e-cigarettes in their youth or early adulthood, they do not get entirely addicted to the product and are able to quit after the "experimenting phase", which could explains the rise in the former use population.

Age Restriction to Flavored ENDS Products

Our model shows that restricting youth access to flavored ENDS products has no effect on adult's tobacco product use pattern in 2025. This result is consistent with a systematic review conducted in 2002, concluding that the laws restricting youth access to cigarettes on prevalence of smoking among teens is not effective.[14] While some studies attribute this failure the low level

of compliance achieved by the community retailers, the systematic review also found no detectable relationship between the level of merchant compliance and 30-day or regular smoking prevalence.[14,30] On the other hand, first use of a flavored tobacco product has been reported to be associated with being a current tobacco user and therefore restricting access to the underage should be able to reduce tobacco use. [31] However, a simulation study found that while a retail-oriented youth access policy has the ability to affect youth smoking rates in the short term, its ability to reduce youth smoking is limited.[16] It has been suggested that while many strategies of youth tobacco control might look promising, they might need to be conducted in a coordinated way to take advantage of potential synergies across interventions.[15] Our model projection leads us to believe that restricting youth access to flavored ENDS products may be one of these strategies. Additionally, while its direct effect is negligible on its own, it might also act by changing social norms that our model did not account for. Youth access restriction has been one of the most popular regulatory tools to reduce smoking and it might still have a role in reducing smoking initiation and prevalence, but it might better act as a secondary policy, used to facilitate another policy with a stronger influence. Alternatively, if the age restriction can be upgraded to a full-on flavor ban in the ENDS, like the 2009 flavor ban in cigarettes, it could drive the flavored ENDS users to quit smoking and prevent adolescents from using to begin with.

Menthol Ban

In our model, the menthol ban is effective in pushing more combustible users to quit smoking within the 10-year time frame without any substantial change to the e-cigarette use population. However, the policy doesn't seem to prevent the initiation of tobacco product use, since there is no change in the projected never use population. While flavored tobacco products

are often people's choice for first use of tobacco product, popularity and availability of e-cigarettes could haven mitigated the policy's impact on the prevention of tobacco product use initiation.[32] However, even the additional smoking cessation resulted from this policy indicates reduction of preventable death .

We did see a slight decrease in the e-cigarette and dual use population. While the decrease is not substantial, the e-cigarette use prevalence is expected to rise, given people are more likely to switch to e-cigarette use in this scenario. In addition, while we didn't alter the transition probabilities from combustible to dual use, prevalence of dual use should be impacted by the policy as well since e-cigarette users are more likely to become dual users than combustible product users. These changes in the opposite direction from expected suggests that switching to e-cigarettes is acting as an effective cessation tool, especially among adults. Promoting e-cigarette use among adult smokers may help reduce the prevalence of tobacco use overall. However, the effects may be cancelled out if the e-cigarette use prevalence continue to rise among teens.

We do acknowledge that actual behaviors may contrast with planned behaviors. In the Ontario study, 14.5% of the menthol users expected to quit smoking and 5.8% expected to switch to alternative flavored products such as e-cigarettes, compared with 29.1% eventually quit and another 29.1% that switched. [17] Therefore the actual results may differ from what the model predicted and we may actually see more quitters but also more e-cigarette users.

In addition, another study on Ontario's menthol ban has found that tobacco companies might attempt to maintain menthol to maintain menthol smokers via several strategies, including promotion of alternative tobacco products with menthol and directing smokers to non-menthol

alternatives whose packaging connoted menthol-like qualities. [33] Therefore, the response from the tobacco companies could also attenuate the effect of a menthol ban policy on promoting smoke cessation among menthol cigarette users.

Strengths and Limitations

This model captures comprehensive patterns of change for the tobacco product use prevalence. The model was calibrated to several years of recent tobacco product use and we observed acceptable fit between the model and observed data. While the model is based on input from multiple studies, robustness of the results is assessed through sensitivity analysis. Sensitivity analyses suggested that varying key parameters did not substantially affect predicted product use patterns after 10 years.

A key limitation of this model is the uncertainty about future trends in e-cigarette use. There has been a vast increase in e-cigarette use and initiation, especially among the youth and young adults. The transition probabilities from 2013-2015 data might not reflect the real-world transition taking place. In addition, because our model requires the states to be mutually exclusive, we were not able to use directly the tobacco use prevalence in the reports to calibrate and validate our model. As a result, the calculation and adjustment of the final proportions of tobacco use relies on several assumptions, which could be avoided if there are more data available.

Recommendations for Further Research

Future research should focus on gathering more data to acquire better estimates of the e-cigarette use and associated transition probabilities, along with more detailed survey results to

calibrate the model towards. For example, the Wave 3 data of the PATH study should provide more insights to the change in transition probabilities associated with e-cigarette use.

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Appendices

Table A1. Combustible use initiation and cessation rate prediction parameters

	Never to Combustible use			
	Intercept		Beta	
Age	Male	Female	Male	Female
18	3.077016	2.121782	-0.00151	-0.00104
19	2.603982	1.652312	-0.00128	-0.00081
20	2.156003	1.300198	-0.00106	-0.00064
21	1.781623	1.049829	-0.00088	-0.00052
22	1.470477	0.859864	-0.00072	-0.00042
23	1.212936	0.707297	-0.0006	-0.00035
24	0.999311	0.582591	-0.00049	-0.00029
25	0.821727	0.480075	-0.0004	-0.00024
26	0.673343	0.395166	-0.00033	-0.00019
27	0.546409	0.323285	-0.00027	-0.00016
28	0.434396	0.260667	-0.00021	-0.00013
29	0.33319	0.204827	-0.00016	-0.0001
30	0.241014	0.154479	-0.00012	-7.59E-05
31	0.15851	0.109592	-7.75E-05	-5.37E-05
32	0.089852	0.072149	-4.36E-05	-3.53E-05
33	0.037628	0.043296	-1.79E-05	-2.10E-05
34	0.002361	0.023258	-5.21E-07	-1.12E-05
35	-0.01739	0.011355	9.16E-06	-5.34E-06
36	-0.02447	0.006205	1.26E-05	-2.84E-06
37	-0.02281	0.005781	1.17E-05	-2.68E-06
38	-0.01635	0.007992	8.37E-06	-3.82E-06
39	-0.00832	0.011103	4.32E-06	-5.40E-06
40	-0.00095	0.013877	6.16E-07	-6.80E-06
41	0.004466	0.015578	-2.11E-06	-7.67E-06
42	0.007526	0.015971	-3.66E-06	-7.88E-06
43	0.008553	0.015222	-4.18E-06	-7.52E-06
44	0.008162	0.013671	-4.00E-06	-6.76E-06
45	0.006982	0.011688	-3.43E-06	-5.78E-06
46	0.005524	0.009588	-2.71E-06	-4.74E-06
47	0.004136	0.007621	-2.03E-06	-3.76E-06
48	0.00298	0.005914	-1.46E-06	-2.92E-06
49	0.002098	0.004511	-1.02E-06	-2.23E-06
50	0.001467	0.003415	-7.14E-07	-1.68E-06
51	0.001036	0.002576	-5.03E-07	-1.27E-06
52	0.000751	0.001965	-3.64E-07	-9.67E-07
53	0.000566	0.00153	-2.74E-07	-7.53E-07
54	0.000447	0.001246	-2.16E-07	-6.13E-07
55	0.000372	0.001055	-1.80E-07	-5.19E-07
56	0.000322	0.000937	-1.56E-07	-4.62E-07
57	0.000287	0.000868	-1.40E-07	-4.28E-07
58	0.000259	0.000817	-1.26E-07	-4.03E-07
59	0.000233	0.000782	-1.14E-07	-3.87E-07
60	0.000206	0.000749	-1.01E-07	-3.70E-07
61	0.000178	0.000708	-8.73E-08	-3.50E-07
62	0.00015	0.000662	-7.35E-08	-3.28E-07
63	0.000122	0.000609	-6.00E-08	-3.02E-07
64	9.68E-05	0.000551	-4.75E-08	-2.73E-07
65	7.41E-05	0.00049	-3.63E-08	-2.42E-07

	Combustible to Former use			
	Intercept		Beta	
Age	Male	Female	Male	Female
18	-1.47794	-1.79534	0.000749	0.000909
19	-1.41274	-1.70621	0.000716	0.000865
20	-1.34766	-1.61884	0.000684	0.000821
21	-1.28272	-1.53321	0.000652	0.000778
22	-1.21791	-1.44929	0.000619	0.000736
23	-1.15321	-1.36705	0.000587	0.000695
24	-1.08865	-1.28647	0.000555	0.000655
25	-1.0242	-1.20752	0.000523	0.000615
26	-0.95988	-1.13017	0.000491	0.000577
27	-0.89568	-1.0544	0.000459	0.000539
28	-0.83159	-0.98019	0.000427	0.000502
29	-0.76763	-0.9075	0.000395	0.000465
30	-0.70377	-0.83632	0.000364	0.00043
31	-0.63996	-0.7667	0.000332	0.000395
32	-0.57583	-0.69901	0.0003	0.000361
33	-0.51096	-0.63363	0.000268	0.000329
34	-0.44499	-0.57088	0.000235	0.000297
35	-0.37755	-0.51103	0.000201	0.000267
36	-0.30832	-0.45429	0.000167	0.000239
37	-0.23702	-0.40085	0.000131	0.000212
38	-0.16338	-0.35084	9.45E-05	0.000187
39	-0.08722	-0.3044	5.66E-05	0.000164
40	-0.00834	-0.26162	1.73E-05	0.000143
41	0.073037	-0.22257	-2.3E-05	0.000123
42	0.155552	-0.18708	-6.4E-05	0.000106
43	0.237716	-0.15497	-0.00011	8.99E-05
44	0.318271	-0.1261	-0.00015	7.56E-05
45	0.396167	-0.10038	-0.00018	6.29E-05
46	0.470542	-0.07773	-0.00022	5.18E-05
47	0.540676	-0.05812	-0.00026	4.22E-05
48	0.605947	-0.04158	-0.00029	3.42E-05
49	0.665768	-0.02815	-0.00032	2.77E-05
50	0.719515	-0.01794	-0.00034	2.29E-05
51	0.766757	-0.01103	-0.00037	1.98E-05
52	0.808116	-0.00727	-0.00039	1.82E-05
53	0.844322	-0.00648	-0.00041	1.82E-05
54	0.875953	-0.00849	-0.00042	1.96E-05
55	0.903498	-0.01309	-0.00043	2.24E-05
56	0.927405	-0.0201	-0.00045	2.63E-05
57	0.948134	-0.02928	-0.00046	3.14E-05
58	0.966201	-0.04037	-0.00046	3.74E-05
59	0.98222	-0.05305	-0.00047	4.43E-05
60	0.996944	-0.06697	-0.00048	5.18E-05
61	1.011114	-0.08176	-0.00048	5.98E-05
62	1.024849	-0.0974	-0.00049	6.82E-05
63	1.038098	-0.1139	-0.0005	7.7E-05
64	1.050804	-0.13132	-0.0005	8.63E-05
65	1.062912	-0.14967	-0.00051	9.61E-05

Table A2. Predicted tobacco product use prevalence of 18-year-olds from 2015 to 2025

Year	Combustible only	E-cigarette only	Dual use	Never use	Former use
2015	0.119	0.031	0.059	0.567	0.223
2016	0.109	0.037	0.054	0.577	0.223
2017	0.099	0.042	0.049	0.588	0.223
2018	0.089	0.048	0.043	0.598	0.222
2019	0.079	0.053	0.038	0.608	0.222
2020	0.069	0.059	0.033	0.618	0.222
2021	0.059	0.065	0.028	0.628	0.221
2022	0.049	0.070	0.022	0.638	0.221
2023	0.039	0.076	0.017	0.648	0.221
2024	0.028	0.081	0.012	0.658	0.220
2025	0.018	0.087	0.006	0.668	0.220

Table A3. Predicted tobacco product use prevalence of 18-year-olds with age restriction to flavored ENDS products from 2015 to 2025

Year	Combustible only	E-cigarette only	Dual use	Never use	Former use
2015	0.119	0.026	0.059	0.573	0.223
2016	0.109	0.030	0.054	0.584	0.223
2017	0.099	0.035	0.049	0.595	0.223
2018	0.089	0.040	0.043	0.606	0.222
2019	0.079	0.044	0.038	0.617	0.222
2020	0.069	0.049	0.033	0.628	0.222
2021	0.059	0.054	0.028	0.639	0.221
2022	0.049	0.058	0.022	0.650	0.221
2023	0.039	0.063	0.017	0.661	0.221
2024	0.028	0.068	0.012	0.672	0.220
2025	0.018	0.072	0.006	0.683	0.220

Table A4. Transition probability matrix with menthol ban

	Combustible only	E-cigarette only	Dual use	Former use	Never use
18-24 years old					
Combustible only	#	0.02925†	0.176	* + 0.0425†	0
E-cigarette only	0.212	#	0.215	0.265	0
Dual use	0.371	0.059	#	0.122	0
Former use	0.091	0.022	0.029	#	0
Never use	*	0.023	0.009	0	#
25+ years old					
Combustible only	#	0.02125†	0.106	* + 0.0425†	0
E-cigarette only	0.135	#	0.147	0.205	0
Dual use	0.433	0.058	#	0.074	0
Former use	0.040	0.005	0.003	#	0
Never use	*	0.002	0.0005	0	#

Complement of the row
* Calculated based on age, sex, and year for each simulated individual
† Different from probabilities in the current policy environment

Table A5. Model validation results

	2014		2017	
	Actual*	Simulated	Actual*	Simulated
Combustible only	0.147	0.144	0.146	0.143
Any Combustible	0.207	0.205	0.184	0.183
E-cigarette only	0.019	0.017	0.021	0.018
Any E-cigarette	0.039	0.037	0.033	0.032
Dual use	0.067	0.068	0.043	0.044
Former use	0.223	0.224	0.217	0.262
Never use	0.544	0.547	0.574	0.531
Non use	0.761	0.771	0.786	0.793

* The actual results are based on the *Tobacco Use Among Adults, 2013-2014 & 2017*, but adjusted to represent tobacco use pattern only among 18-65-year-olds.

Figure A1. Smoking initiation and cessation rates by age and sex from 2005 to 2015.

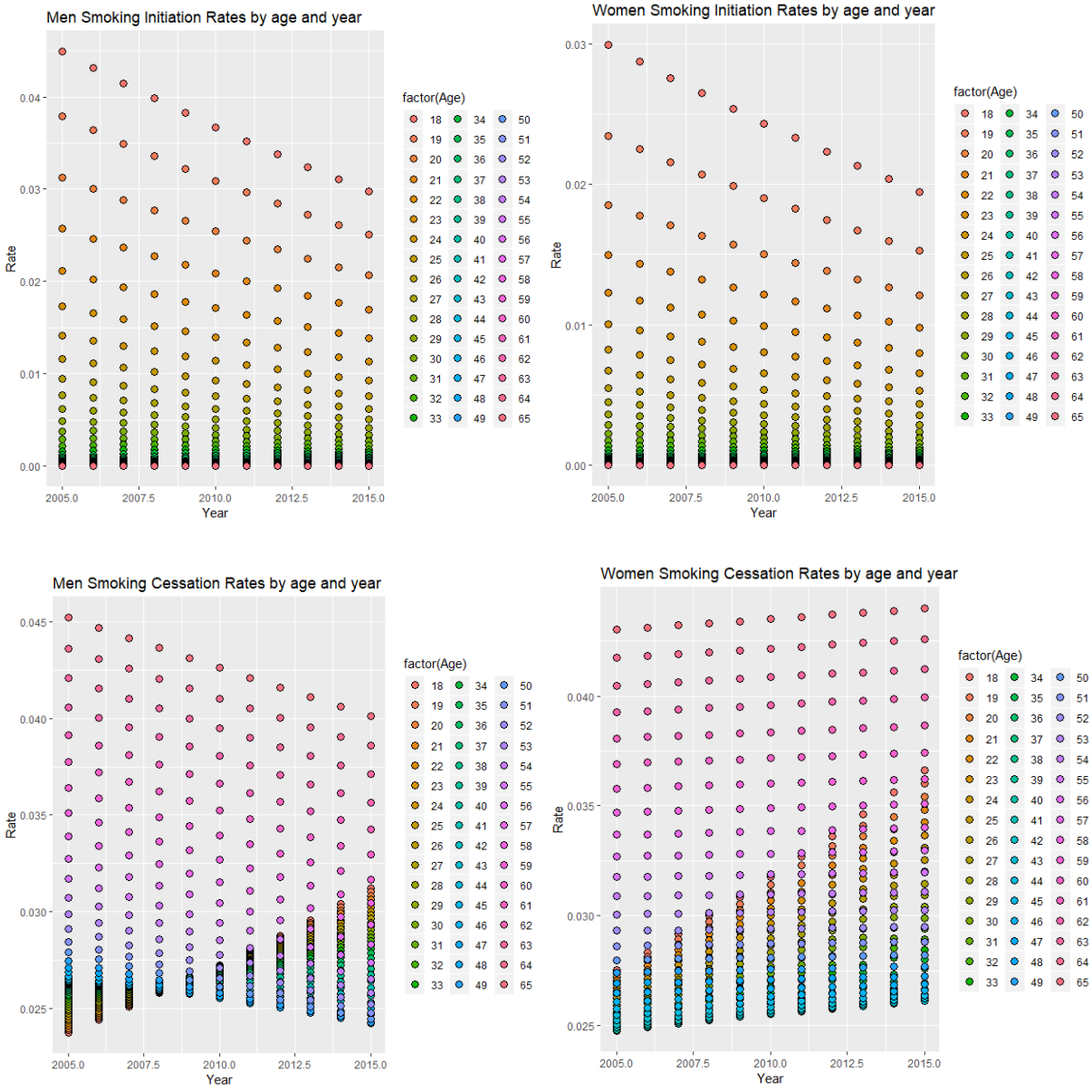

Figure A2. Observed and Extrapolated ratio of never smoker over former smoker by year

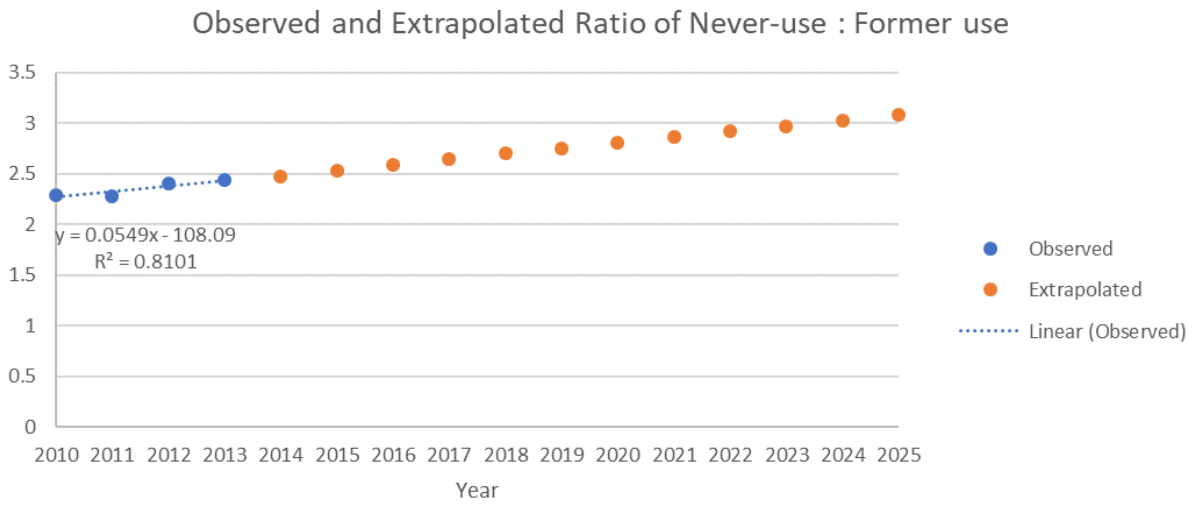

Figure A3. Percentage of population aged 10-64 years old by age and sex in 2015

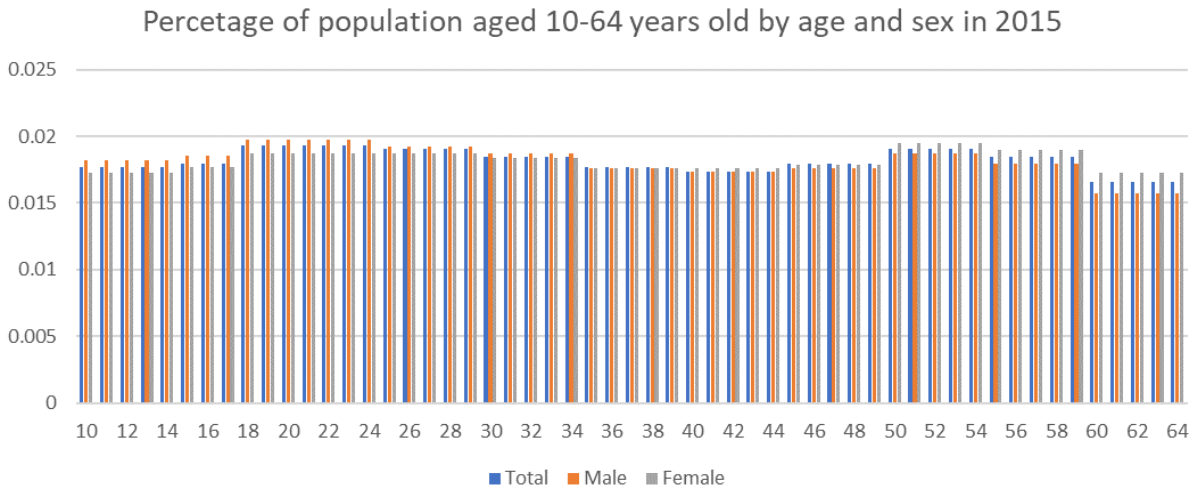

Figure A4. Tobacco use pattern from 2015 to 2025 with age restriction to flavored ENDS products.

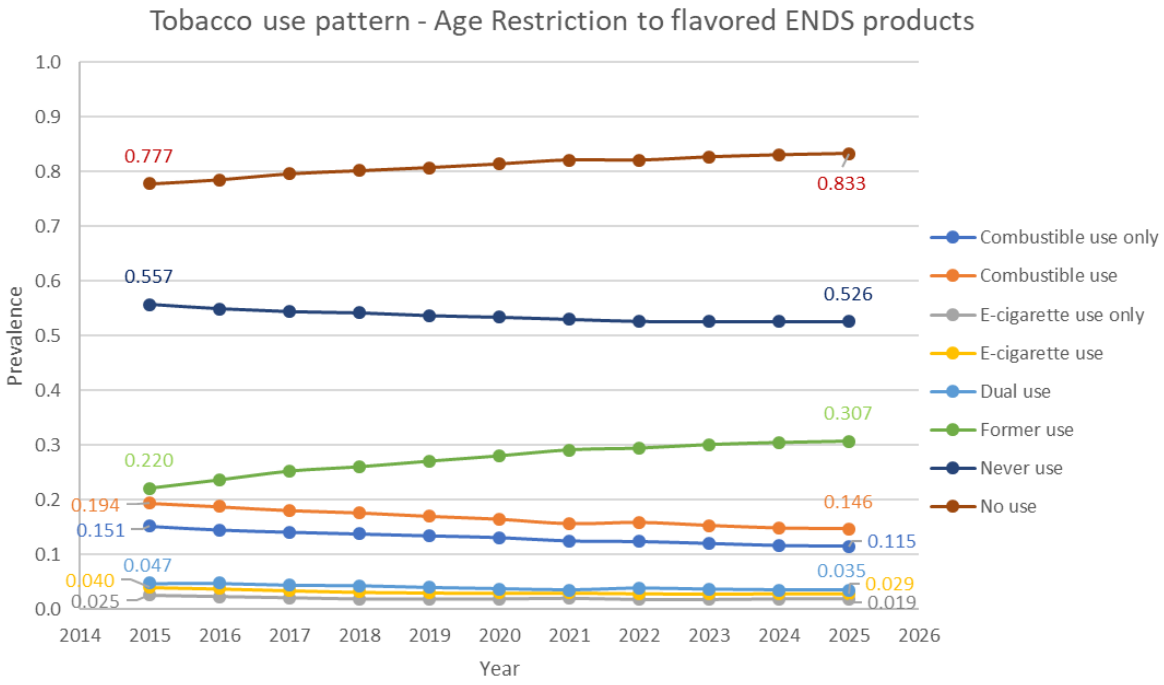

Figure A5. Tobacco use pattern from 2015 to 2025 with menthol ban

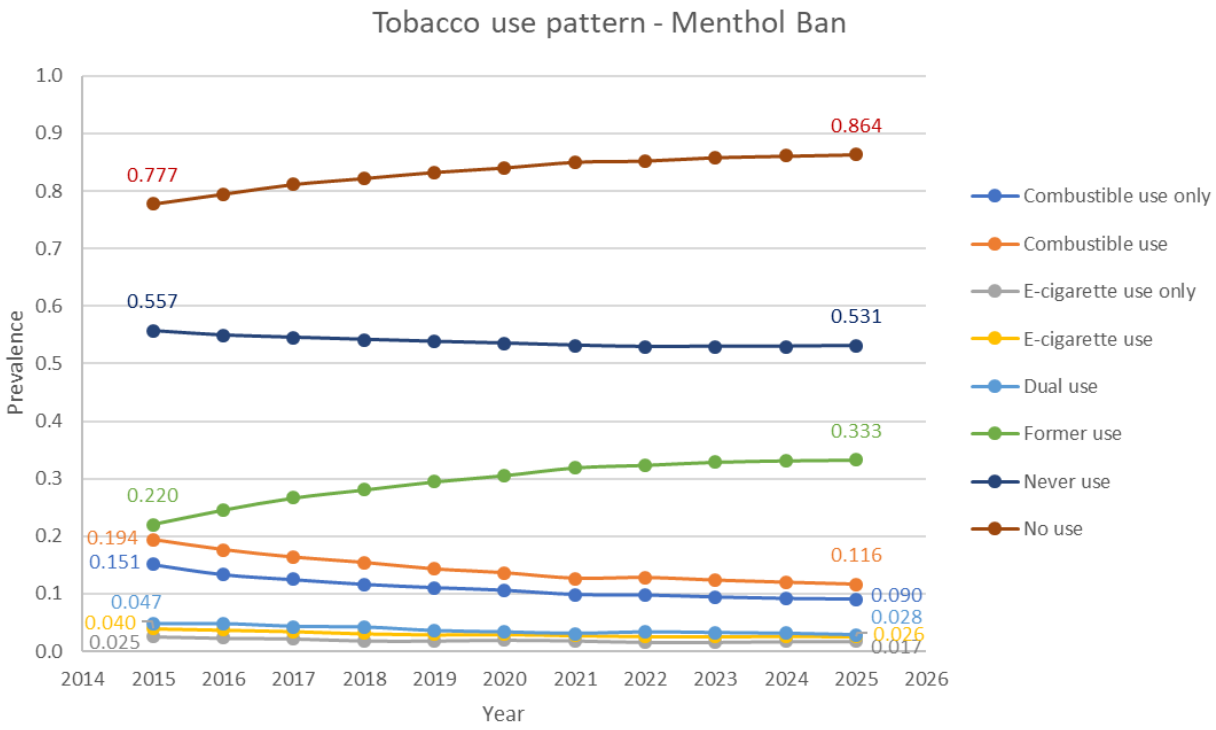

Figure A6. Results from Sensitivity Analysis