The US SimSmoke tobacco control policy model of smokeless tobacco and cigarette use

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Abstract

Background: Smokeless tobacco (SLT) prevalence had been declining in the US prior to 2002 but has since increased. Knowledge about the impact of tobacco control policies on SLT and cigarette use is limited. This study examines the interrelationship between policies, cigarette use, and SLT use by applying the SimSmoke tobacco control policy simulation model.

Methods: Using data from large-scale Tobacco Use Supplement and information on policies implemented, US SimSmoke was updated and extended to incorporate SLT use. The model distinguishes between exclusive SLT and dual use of SLT and cigarettes, and considers the effect of implementing individual and combined tobacco control policies on smoking and SLT use, and on deaths attributable to their use. After validating against Tobacco Use Supplement (TUS) survey data through 2015, the model was used to estimate the impact of policies implemented between 1993 and 2017.

Results: SimSmoke reflected trends in exclusive cigarette use from the TUS, but over-estimated the reductions, especially among 18–24 year olds, until 2002 and under-estimated the reductions from 2011 to 2015. By 2015, SimSmoke projections of exclusive SLT and dual use were close to TUS estimates, but under-estimated reductions in both from 1993 to 2002 and failed to estimate the growth in male exclusive SLT use, especially among 18–24 year olds, from 2011 to 2015. SimSmoke projects that policies implemented between 1993 and 2017 reduced exclusive cigarette use by about 35%, dual use by 32.5% and SLT use by 16.5%, yielding a reduction of 7.5 million tobacco-attributable deaths by 2067. The largest reductions were attributed to tax increases.

Conclusions: Our results indicate that cigarette-oriented policies may be effective in also reducing the use of other tobacco products. However, further information is needed on the effect of tobacco control policies on exclusive and dual SLT use and the role of industry.

Keywords: Smokeless tobacco, Tobacco control policies, Simulation model

Background

Adult smoking prevalence in the US declined from 26% in 1993 to 14% in 2015 [1]. Much of that decrease can be attributed to the implementation of tobacco control policies, including smoke-free air laws, marketing restrictions, media campaigns, treatment and tax increases [2, 3]. While smoking prevalence has declined, the use of other tobacco products, such as little cigars or smokeless tobacco (SLT), and of e-cigarettes has increased [4–7]. Much of that is multi-product use, of which 60% includes cigarettes [7]. Although male SLT use had declined in the US from 4.2% in 1993 to 2.8% in 2002 [8, 9], it increased to 3.0% by 2011 [6, 10, 11], with snuff sales increased by 65% [12]. SLT use has been shown to be a direct cause of oral and esophageal cancer, and may also cause heart disease, gum disease and oral lesions [13]. With concerns about the health effects and increasing use of SLT, some states have directed policies at reducing SLT use, including increased SLT taxes, educational campaigns, and cessation treatment [14, 15]. In addition, the 2009 Family Smoking
Prevention and Tobacco Control Act (FSPTCA) authorized the Food and Drug Administration to regulate the marketing, promotion and sale of cigarettes and SLT.

Policies directed at reducing SLT use may also impact cigarette use. For example, cigarette use may increase if youth and young adults initiate smoking instead of SLT or if smokers are discouraged from using SLT to help quit cigarette use. However, SLT-oriented policies could reduce cigarette use if the two tend to be used together (i.e. dual use) and the policies encourage cessation, or if SLT acts as a gateway to cigarette smoking. Similarly, policies directed at reducing cigarette use may discourage SLT use if the two are used together or may encourage SLT use if SLT is used as a cigarette substitute. Policy evaluations have provided limited information on their effects [15]. Knowledge of the policy impacts can help to better design policies towards SLT use, and may have implications for other nicotine delivery products, such as e-cigarettes [16].

This paper employs simulation modeling to examine the inter-relationship of tobacco control policies and patterns of cigarette and SLT use. We adopt the well-established SimSmoke simulation model [2, 3]. The model incorporates population and smoking dynamics and focuses on the major cigarette-oriented tobacco control policies, including taxes, smoke-free air laws, media campaigns, marketing restrictions, cessation treatment policies and youth access enforcement. SimSmoke has been used for advocacy and planning purposes to examine the impact of past and projected future policies individually and in combination [17]. The model has been developed and validated for over 25 nations and 8 states with a wide range of different policy changes [2, 18–26].

The SimSmoke model is extended here to incorporate SLT use, distinguishing between exclusive SLT and dual (both cigarette and SLT) use. We consider the effect of tobacco control policies implemented between 1993 and 2017 on cigarette and SLT use and on the deaths attributed to that use.

**Methods**

The model begins with the 1993 population distinguished by age and gender and further distinguished as never tobacco users, and both current and former users among exclusive cigarette, exclusive SLT, and dual users. As shown in Fig. 1, cigarette and SLT use age change over time through modules for population, tobacco use, tobacco-attributable deaths and separate modules for each policy.

**Population**

Population data were obtained by single age (0 through 85) from the Census Bureau for 1993–2013 [27–29] and for 2016–2067 [30] from the Census Bureau’s Population Projections Program. Starting with the population in 1993, the population evolves through births, deaths and net immigration, with births up to age 14 based on the obtained population data and older age groups subject mortality rates from the CDC [31]. Mortality rates by age and gender were averaged by age group over the years 1999 through 2013 and then smoothed using
Tobacco use

Individuals evolve from never tobacco users to current tobacco users through smoking and SLT initiation. Tobacco users become former users through quit rates, but may return to their prior tobacco use state through relapse. A discrete time, first order Markov process was assumed for these transitions.

Baseline estimates of exclusive smoking, exclusive SLT and dual use status by age and gender were obtained from the nationally-representative 1992/3 Tobacco Use Supplement (TUS) of the Current Population Survey [33]. Current smokers were defined as individuals who have smoked more than 100 cigarettes in their lifetime and currently smoke cigarettes either daily or on some days. A question was asked regarding whether the individual “regularly” used SLT. Those regular SLT users were further distinguished as dual users (with cigarette use) and exclusive SLT users. Former users were defined as those who met the respective definitions for use, but reported no current use. Former smokers were split into exclusive smokers and former dual users using the age-specific ratio of exclusive smokers and dual users, and former exclusive SLT users were estimated by the ratio of former to current smokers. Former exclusive smokers and dual users were distinguished by years since quitting (<1, 1, 2, ..., 15, >15 years). Since former SLT users were not asked about years since quitting, the initial percentages were assumed the same as for former smokers.

Because evidence on initiation and early transitions to SLT use from the literature was mixed [34–38] and because the TUS did not provide such information, we employed a measure of net initiation, whereby initiation was measured for each of the three user groups as the difference between the base year prevalence at a given age and base year prevalence at the previous age. Thereby, this measure incorporates initiation, cessation and switching between tobacco products, similar to previous SimSmoke models without the ability to switch products [2, 3]. This method ensures stability and internal consistency of the model. We allowed for initiation through age 30 for males and age 27 for females, the respective ages when net initiation for all three user groups began to decline. Cessation occurs after the last age of net initiation.

Data on smoker quit rates were obtained from the TUS, measured as those who quit in the last year, but not the last 3 months [39]. Since sufficient data to estimate quit rates for exclusive SLT and dual users were not available from the TUS, we considered previous literature. Studies [40–42] generally found that quit rates were at least as high among SLT as cigarette users. With some exceptions [43], studies obtained similar quit rates for dual users and exclusive smokers [42, 44, 45]. Quit rates were set the same for dual and exclusive SLT users as for all smokers. Age- and gender-specific relapse rates by years quit were based on the rates for smokers [46–49]. Finally, since studies indicated limited switching between SLT and cigarettes, except at younger ages [40–42], switching only occurred through net initiation.

Tobacco-attributable deaths

Relative risk estimates for current and former smokers by age and gender were based on the Cancer Prevention Study II [48, 50, 51], as in previous US SimSmoke models [2, 3]. Relative risks for dual users may be less than for exclusive smokers due to reduced quantity smoked [43], but studies have found similar risks [52, 53] except with large quantity reductions [54]. We assigned the same risks to exclusive cigarette and dual users, so that risks decline at the same rate with years since quitting [48, 50, 51]. We estimate an exclusive SLT relative mortality risk of 1.15 based on a large-scale US study [55].

To obtain smoking-attributable deaths, the number of exclusive smokers at each age is multiplied by the excess mortality risks (exclusive smokers death rate minus never smokers death rate) to obtain attributable deaths by age, and then summed over ages. The same procedure was applied to former exclusive smokers and summed over current and former smokers. Separate estimates were derived in the same way for exclusive SLT and for dual users.

Policies

The model was initialized with 1993 policy levels, and incorporates US and state policy changes occurring between 1993 and 2017. Policy descriptions and effect sizes are shown in Table 1. Policies are generally modelled as having immediate effects on prevalence rates and ongoing effects through initiation and cessation rates. When more than one policy is in effect, the effects are multiplicatively applied as percent changes, subject to synergies (e.g., through publicity from media campaigns, see Table 1).

In the tax module [56], prices were modeled as having constant proportional effects (i.e., constant price elasticities) with respect to price, as derived from demand studies. Based on previous reviews [56, 57], the model assigns a prevalence elasticity for exclusive cigarette and dual use of –0.4 through age 17; –0.3 for ages 18 to 24; –0.2 for ages 25 to 34; –0.1 for ages 35 to 64; and –0.2
| Policy | Description | Cigarette Effect Size$^a$ | Smokeless Tobacco Effect Size$^b$ |
|--------|-------------|---------------------------|-----------------------------------|
| Tax Policies [56, 67, 98, 99] | | Elasticities$^c$ | |
| Cigarette price/tax | The effect of taxed is directly incorporated through average US price (including generics), with separate prices for cigarette and SLT. The price elasticity is used to convert the % price changes into effect sizes. The dual price is computed as 4/5 of the cigarette price + 1/5 SLT price | $-0.4$ ages 10–17 | Same |
| | | $-0.3$ ages 18–24 | Same |
| | | $-0.2$ ages 25–34 | Same |
| | | $-0.1$ ages 35–64 | Double |
| | | $-0.2$ ages 65 | Same |
| Smoke-Free Air Policies [62] | | | |
| Worksites smoking ban | Ban in all indoor worksites, with strong public acceptance and enforcement of laws (reduced by 1/3 if allowed in ventilated areas and by 2/3 if allowed in common areas) | $-6\%$ | One-fourth |
| Restaurants smoking ban | Ban in all indoor restaurants (reduced by half if partial) | $-2\%$ | One-fourth |
| Bars smoking ban | Ban in all indoor (reduced by half if partial) | $-1\%$ | One-fourth |
| Other place bans | Ban in 3 out of 4 government buildings, retail stores, public transportation, and elevators | $-1\%$ | One-fourth |
| Enforcement | Government agency enforces the laws | Effects reduced 50% absent enforcement | Same |
| Mass Media Campaigns [65] | | | |
| High publicity media campaign | Campaign publicized heavily on TV and at least some other media, with a social marketing approach | $-6.5\%$ | Half |
| Moderate publicity media campaign | Campaign publicized sporadically on TV and at least some other media | $-3.25\%$ | Half |
| Low publicity media campaign | Campaign publicized only sporadically in newspaper, billboard, or some other media | $-1.625\%$ | Half |
| Marketing Restrictions [67, 68] | | | |
| Comprehensive marketing ban | Ban is applied to television, radio, print, billboard, in-store displays, sponsorships and free samples (all indirect marketing) | $-5\%$ prevalence, $-8\%$ initiation, $+4\%$ cessation | Same |
| Moderate advertising ban | Ban is applied to all media (television, radio, print, billboard) plus one indirect marketing medium | $-3\%$ prevalence, $-4\%$ initiation, $+2\%$ cessation | Same |
| Weak advertising ban | Ban is applied to some television, radio, print, and billboard | $-1\%$ prevalence and initiation only | Same |
| Enforcement | Government agency enforces the laws | Effects reduced 50% absent enforcement | Same |
| Health Warnings [69] | | | |
| Strong | Labels are large, bold and graphic, and cover at least 30% of pack | $-4\%$ prevalence, $-2\%$ initiation, $+10\%$ cessation | Same |
| Moderate | Laws cover 1/3 of package, not bold or graphic | $-2\%$ prevalence & initiation, $+2\%$ cessation | Same |
| Weak | Laws cover less than 1/3 of package, not bold or graphic | $-1\%$ prevalence & initiation, $+2\%$ cessation | Same |
| Cessation Treatment Policies [70] | | | |
| Availability of pharmacotherapies | Legality of nicotine replacement therapy, Wellbutrin and varenicline | $-1\%$ prevalence, $+6\%$ cessation$^d$ | Half |
| Proactive quitline | A proactive quitline with publicity throughout the media campaign with no cost nicotine replacement therapy | $-1\%$ prevalence, $+8\%$ cessation$^d$ | Half |
Table 1 Policy Inputs for Cigarette and Smokeless Tobacco in SimSmoke Simulation Model (Continued)

| Policy                        | Description                                                                                                                                                                                                 | Cigarette Effect Size<sup>a</sup>                                      | Smokeless Tobacco Effect Size<sup>b</sup> |
|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|------------------------------------------|
| Subsidization pharmatherapy   | Payments to cover pharmatherapy and behavioral cessation treatment                                                                                                                                         | −2.25% prevalence, +12% cessation<sup>d</sup>                           | Half                                     |
| Brief health care provider interventions | Advice by health care provider to quit and methods provided                                                                                                                                            | −1% prevalence, +8% cessation<sup>d</sup>                              | Half                                     |
| All of the above              | Complete availability and reimbursement of pharma- and behavioral treatments, quitlines, and brief interventions                                                                                          | −5.2% prevalence, +43% cessation<sup>d</sup>                           | Half                                     |
| Youth Access Restrictions [73]|                                                                                                                                                                                                             |                                                                         |                                          |
| Strongly enforced             | Compliance checks are conducted 4 times per year per outlet, penalties are potent and enforced with heavy publicity                                                                                     | −16% initiation and prevalence for ages 16–17 and −24% ages < 16<sup>d</sup> | Half                                     |
| Well enforced                 | Compliance checks are conducted regularly, penalties are potent, and publicity and merchant training are included                                                                                      | −8% initiation and prevalence for ages 16–17 and −12% ages < 16<sup>d</sup> | Half                                     |
| Low enforcement               | Compliance checks are conducted sporadically, penalties are weak                                                                                                                                         | −2% initiation and prevalence for ages 16–17 and −3% ages < 16<sup>d</sup> | Half                                     |
| Vending machine restrictions  | Total ban                                                                                                                                                                                                   | Enforcement effects increase by 8%<sup>d</sup>                         | Half                                     |
| Self-service restrictions     | Total ban                                                                                                                                                                                                   | Enforcement effects increase by 4%<sup>d</sup>                         | Half                                     |
| Publicity                     | Media campaigns directed at youth use                                                                                                                                                                     | Enforcement effects increase by 10%<sup>d</sup>                        | Half                                     |

<sup>a</sup> Unless otherwise indicated, the effects are in terms of the reduction in prevalence during the first year, the reduction in initiation, and increase in first year quit rates during the years that the policy is in effect

<sup>b</sup> Effect sizes are relative to cigarette effect sizes and applied to exclusive cigarette use only unless otherwise indicated

<sup>c</sup> Elasticities translate into effect sizes through percentage change in price

<sup>d</sup> Effect size differs for exclusive SLT and for dual use

for age 65 and older. Price elasticities for adult SLT use have generally ranged from −0.2 to −0.8 [15]. The price prevalence elasticities for exclusive SLT use were estimated at −0.4 for those through age 17, −0.3 for ages 18–24, and −0.2 for ages 25 and above. Cigarette prices were measured by national average cigarette retail prices (including generics) [58] for 1993–2014 with the 2014 price adjusted upward for 2015–2017 to reflect state level tax increases as weighted by the state population. The national average retail prices and manufacturer tax for SLT products through 2014 were measured by the state retail prices and manufacturer taxes weighted by the SLT smoker population [59], using manufacturer sales and quantity shipped in pounds [60], tax data [61], estimated weights per unit [60], and estimated mark-ups. We adjusted the 2014 price upward for 2015–2017 by the state population-weighted tax increase. For SLT users, we used a weighted price, with weights of 80% of the cigarette price and 20% of SLT price [59]. All prices were deflated by the consumer price index to adjust for price inflation.

SimSmoke considers worksites, restaurants, pub and bars, and other public places laws, and the role of enforcement [62]. Studies of SLT use have found a negative relationship to smoke-free air laws [15]. Based on these findings and since smoke-free air laws are not explicitly directed at SLT use, exclusive SLT and dual use effect sizes were set at 25% those of cigarettes. Data on state level smoke-free air laws [63] were weighted by state smoker populations. The enforcement level was set at 80% for all years, as previously developed for US SimSmoke [2, 3].

SimSmoke evaluates media campaigns in terms of overall tobacco control expenditures, much of which are for media campaigns [64]. They are categorized as high, medium, or low levels [65]. Studies have generally found SLT-oriented educational campaigns effective in reducing youth and adults and adult use [15], but due to reduced emphasis on SLT as compared to cigarette-oriented campaigns, exclusive SLT and dual effect sizes were set at 50% that of cigarettes. State per capita expenditures [66] were categorized by levels and weighted by the state smoker population, and were initially categorized as low level in 1993 increasing to medium level by 2004.

SimSmoke considers restrictions on both direct and indirect marketing [67, 68]. While no studies have directly examined the relationship of marketing restrictions to SLT use, awareness of and exposure to SLT advertisements has been associated with increased use [15]. SLT and dual use were assigned the same policy effect sizes as for cigarettes. Restrictions on advertising for both SLT and cigarette use were set at a minimal level from 1993 to 2009, reflecting an earlier media advertising ban,
with enforcement set at 90% [2]. In 2010, they were increased to 25% moderate and 75% minimal, reflecting added 2009 FSPTCA restrictions on sponsorships and coupons, and in publications.

The effectiveness of health warnings depends primarily on their size and whether they include graphics [69]. Limited effectiveness has been found for text-only warnings on SLT packages, but pictorial warnings were associated with less susceptibility to SLT use among youth [70]. Treatment coverage was initiated in stages beginning with minimal in 1997 increasing to moderate by 2007 [74]. A national (active) quitline was implemented at 25% capacity beginning in 2003 increasing in stages to 100% by 2007 [74]. Brief interventions were set at a level of 50% for all years. Most states currently have provisions for SLT advice and treatment, and consequently the policy levels were set the same as for cigarettes.

Youth access enforcement include enforcement, and restrictions on vending machines and self-service. Strongly enforced and publicized youth access laws yield a larger reduction in youth smoking initiation for 10–15 year-olds than for 16–17 year-olds, further enhanced by vending machine and self-service bans [75]. Two studies of youth SLT use [76, 77] found youth access policies affected SLT use, although the effect was weak, and two studies [78, 79] found lower compliance rates for SLT than cigarette purchases. Youth access policy effect sizes for exclusive SLT use were assigned 50% of the effect sizes for cigarettes, while the effects on dual use were assigned the same effect sizes as for exclusive cigarette use. Enforcement levels for both SLT and cigarettes were set at none before 1997, at low-level from 1998 to 2002 and at mid-level since 2003 [6]. Levels for vending machine bans were set at 50% beginning in 1993 [80] increasing to 75% by 2000, and for self-service bans were set at 50% beginning in 1995. Both vending machine and self-service bans were increased to 100% in 2010, reflecting requirements under the 2009 FSPTCA.

Validation
To validate the model, we compared predicted cigarette and SLT prevalence rates (that incorporate policy changes) to the comparable use rates estimated from the 2002, 2010/11 and 2014/15 TUS surveys. Because screening questions on SLT use in the TUS changed from “regular use” to days use, current users from 2002 onward were defined as individuals currently using SLT at least 10 days in the last month [81]. For the years 2002, 2010/11 and 2014/15, we considered whether SimSmoke predictions were within the 95% confidence intervals (CI) from the TUS, assuming a binomial distribution for each use category. We also compared the relative change in prevalence rates from SimSmoke to those from the TUS by sub-periods (1993–2002, 2002–2011, and 2011–2015) and overall (1993–2015).

The effect of past tobacco control policies
Upon validating the model, we estimated the effect of policies on tobacco prevalence and tobacco-attributable deaths. First, we programmed SimSmoke with all policies remaining at their 1993 levels to estimate the counterfactual without any policies implemented. We then subtracted estimates incorporating all implemented policies from those for the counterfactual in order to estimate the net reductions due to the policies implemented since 1993. The contribution of individual policies were estimated by reprogramming SimSmoke to only allow for the change in that policy while holding other policies constant, which was compared to the counterfactual with no policies implemented. The relative reductions for each policy were measured relative to the summed effects of all policies, since the effects with multiple policies depend on assumed synergies and do not sum to one.

Results
Predictions of smoking and SLT prevalence from 1993 to 2014/15
SimSmoke predictions for 1993 to 2015 incorporating policy changes and estimated smoking prevalence from TUS are shown for exclusive cigarette, dual and exclusive SLT users in Table 2.

For the adult population (ages 18 and above), SimSmoke predicted that exclusive male (female) cigarette prevalence fell from 25.6% (22.1%) in 1993 to 14.2% (12.4%) in 2015, while the TUS showed a decline from
## Table 2 Validation: Exclusive Cigarette, Dual and Exclusive SLT Use, SimSmoke Projections vs. Tobacco Use Supplement, by Age and Gender, 1993–2015

### Exclusive Cigarette Use

| Ages     | Source          | 1993 | 2002  | Relative changea  | 2011 | Relative changea | 2015 | Relative changea | 1993–2015 |
|----------|-----------------|------|-------|------------------|------|-----------------|------|-----------------|----------|
| **Male** |                 |      |       | 1993–2002        |      | 2002–2011       |      | 2011–2015       |          | 1993–2015       |
| 18+      | SimSmoke        | 25.6 | 20.2  | −21.3%           | 15.4 | −23.5%          | 14.2 | −8.2%           | −44.7%   |
|          | CPS-TUS         | 25.7 | 22.0  | −14.1%           | 17.1 | −22.5%          | 14.9 | −12.6%          | −41.8%   |
|          | 95% CI          | (21.7, 24.4%) | (16.8, 17.4%) | (14.7, 15.2%) |
| 18–24    | SimSmoke        | 25.1 | 20.4  | −18.7%           | 17.0 | −16.4%          | 16.9 | −1.0%           | −32.8%   |
|          | CPS-TUS         | 25.5 | 26.8  | 5.4%             | 18.7 | −30.2%          | 15.6 | −16.7%          | −38.7%   |
|          | 95% CI          | (25.7, 28.0%) | (17.8, 19.7%) | (14.6, 16.6%) |
| 25–34    | SimSmoke        | 29.0 | 23.9  | −17.6%           | 20.2 | −15.4%          | 19.3 | −4.4%           | −33.3%   |
|          | CPS-TUS         | 29.0 | 24.2  | −16.6%           | 21.2 | −12.5%          | 18.0 | −15.2%          | −38.1%   |
|          | 95% CI          | (23.4, 25.0%) | (20.5, 21.9%) | (17.3, 18.7%) |
| 35–54    | SimSmoke        | 29.5 | 22.0  | −25.2%           | 15.7 | −28.8%          | 14.1 | −10.1%          | −52.1%   |
|          | CPS-TUS         | 29.0 | 25.5  | −13.8%           | 19.2 | −24.9%          | 16.7 | −12.9%          | −43.6%   |
|          | 95% CI          | (24.9, 26.1%) | (18.7, 19.6%) | (16.2, 17.2%) |
| 55+      | SimSmoke        | 17.4 | 14.9  | −14.4%           | 11.7 | −21.0%          | 10.4 | −11.5%          | −40.1%   |
|          | CPS-TUS         | 17.5 | 14.5  | −17.0%           | 12.7 | −12.4%          | 12.2 | −4.2%           | −30.3%   |
|          | 95% CI          | (14.0, 15.0%) | (12.3, 13.1%) | (11.8, 12.6%) |
| **Female** |                 |      |       |                  |      |                  |      |                  |          |                  |
| 18+      | SimSmoke        | 22.1 | 17.3  | −21.4%           | 13.4 | −22.5%          | 12.4 | −7.7%           | −43.8%   |
|          | CPS-TUS         | 22.3 | 18.1  | −18.6%           | 14.3 | −21.1%          | 12.8 | −10.9%          | −42.7%   |
|          | 95% CI          | (17.9, 18.4%) | (14.1, 14.5%) | (12.5, 13.0%) |
| 18–24    | SimSmoke        | 23.6 | 19.5  | −17.5%           | 16.3 | −16.3%          | 16.1 | −1.1%           | −31.7%   |
|          | CPS-TUS         | 23.8 | 23.3  | −2.2%            | 15.5 | −33.5%          | 12.1 | −22.0%          | −49.2%   |
|          | 95% CI          | (22.3, 24.3%) | (14.7, 16.4%) | (11.3, 13.0%) |
| 25–34    | SimSmoke        | 27.3 | 20.9  | −23.5%           | 17.6 | −15.8%          | 16.8 | −4.6%           | −38.6%   |
|          | CPS-TUS         | 27.6 | 20.1  | −27.1%           | 17.2 | −14.7%          | 15.0 | −12.9%          | −45.9%   |
|          | 95% CI          | (19.5, 20.8%) | (16.6, 17.8%) | (14.4, 15.6%) |
| 35–54    | SimSmoke        | 25.1 | 19.5  | −22.2%           | 14.2 | −27.1%          | 12.7 | −10.7%          | −49.4%   |
|          | CPS-TUS         | 25.1 | 21.8  | −13.1%           | 17.2 | −20.9%          | 15.6 | −9.6%           | −37.9%   |
|          | 95% CI          | (21.3, 22.2%) | (16.8, 17.6%) | (15.2, 16.0%) |
| 55+      | SimSmoke        | 14.4 | 12.1  | −15.6%           | 9.8  | −18.9%          | 9.1  | −7.8%           | −36.9%   |
|          | CPS-TUS         | 14.8 | 11.4  | −22.5%           | 10.1 | −12.2%          | 9.8  | −2.2%           | −33.4%   |
|          | 95% CI          | (11.0, 11.8%) | (9.7, 10.4%) | (9.5, 10.1%) |
| **Dual use** |                 |      |       |                  |      |                  |      |                  |          |                  |
| **Male** |                 |      |       |                  |      |                  |      |                  |          |                  |
| 18+      | SimSmoke        | 1.0  | 0.9   | −14.6%           | 0.7  | −16.4%          | 0.7  | −5.7%           | −32.6%   |
|          | CPS-TUS         | 1.0  | 0.5   | −47.0%           | 0.5  | −11.4%          | 0.5  | 0.0%           | −53.0%   |
|          | 95% CI          | (0.5, 0.6%) | (0.4, 0.5%) | (0.4, 0.5%) |
| 18–24    | SimSmoke        | 2.2  | 1.5   | −33.5%           | 1.3  | −8.8%           | 1.3  | −0.3%           | −39.5%   |
|          | CPS-TUS         | 2.3  | 1.1   | −52.0%           | 1.1  | 0.5%           | 1.1  | 0.0%           | −51.7%   |
|          | 95% CI          | (0.8, 1.4%) | (0.9, 1.4%) | (0.8, 1.4%) |
| 25–34    | SimSmoke        | 1.4  | 1.4   | 0.7%             | 1.0  | −31.9%          | 0.9  | −1.7%           | −32.6%   |
| Ages | Source | 1993 | 2002 | Relative change\(^a\) | 2011 | Relative change\(^a\) | 2015 | Relative change\(^a\) | 2011–2015 | Relative change\(^a\) | 1993–2015 |
|------|--------|------|------|---------------------|------|---------------------|------|---------------------|-------------|---------------------|-----------|
|      |        |      |      |                     |      |                     |      |                     |             |                     |           |
|      |        |      |      | 1993–2002          |      | 2002–2011          |      | 2011–2015          |             | 1993–2015          |           |
| 55+  | SimSmoke | 0.5% | 0.4% | 23.9%              | 0.3% | 14.8%              | 0.3% | 0.2%               | 8.8%        | 5.4%               |           |
|      | CPS-TUS | 0.5% | 0.2% | 64.3%              | 0.2% | 11.1%              | 0.1% | 6.7%               | 30%         | 17.8%              |           |
|      |         |      |      | 95% CI (0.1, 0.2%) |      | (0.1, 0.2%)        |      | (0.1, 0.2%)        |             | (0.1, 0.2%)        |           |
| Female |        |      |      |                     |      |                     |      |                     |             |                     |           |
| 18+  | SimSmoke | 0.05% | 0.03% | 33.3%              | 0.02% | 32.4%              | 0.02% | 13.2%              | 60.9%       |           |
|      | CPS-TUS | 0.05% | 0.02% | 62.5%              | 0.01% | 44.3%              | 0.02% | 100.0%             | 58.2%       |           |
|      |         |      |      | 95% CI (0.01, 0.03%) |      | (0.01, 0.02%)     |      | (0.01, 0.03%)     |             | (0.01, 0.03%)     |           |
| 18–24 | SimSmoke | 0.05% | 0.03% | 32.2%              | 0.03% | 9.1%               | 0.03% | 0.48%              | 38.7%       |           |
|      | CPS-TUS | 0.05% | 0.01% | 77.1%              | 0.08% | 55.5%              | 0.02% | 75.0%              | 62.5%       |           |
|      |         |      |      | 95% CI (0.00, 0.03%) |      | (0.04, 0.18%)    |      | (0.00, 0.10%)     |             | (0.00, 0.10%)     |           |
| 25–34 | SimSmoke | 0.03% | 0.03% | 2.6%               | 0.02% | 33.4%              | 0.02% | 2.8%               | 36.9%       |           |
|      | CPS-TUS | 0.02% | 0.02% | 63%                | 0.02% | 9.9%               | 0.01% | 50.0%              | 57.8%       |           |
|      |         |      |      | 95% CI (0.00, 0.04%) |      | (0.01, 0.06%)    |      | (0.00, 0.05%)     |             | (0.00, 0.05%)     |           |
| 35–54 | SimSmoke | 0.06% | 0.03% | 49.1%              | 0.02% | 42.7%              | 0.01% | 18.6%              | 76.3%       |           |
|      | CPS-TUS | 0.06% | 0.02% | 69%                | 0.01% | 43.2%              | 0.03% | 200.0%             | 47.2%       |           |
|      |         |      |      | 95% CI (0.00, 0.03%) |      | (0.00, 0.03%)    |      | (0.01, 0.05%)     |             | (0.01, 0.05%)     |           |
| 55+  | SimSmoke | 0.05% | 0.04% | 26.3%              | 0.02% | 34.0%              | 0.02% | 19.5%              | 60.8%       |           |
|      | CPS-TUS | 0.05% | 0.02% | 66.6%              | 0.00% | 100.0%             | 0.01% | …                 | 81.0%       |           |
|      |         |      |      | 95% CI (0.00, 0.03%) |      | (0.00, 0.02%)    |      | (0.00, 0.03%)     |             | (0.00, 0.03%)     |           |

**Table 2** Validation: Exclusive Cigarette, Dual and Exclusive SLT Use, SimSmoke Projections vs. Tobacco Use Supplement, by Age and Gender, 1993–2015 (Continued)

**Exclusive cigarette use**

### Male

| Ages | Source | 1993 | 2002 | Relative change\(^a\) | 2011 | Relative change\(^a\) | 2015 | Relative change\(^a\) | 2011–2015 | Relative change\(^a\) | 1993–2015 |
|------|--------|------|------|---------------------|------|---------------------|------|---------------------|-------------|---------------------|-----------|
|      |        |      |      |                     |      |                     |      |                     |             |                     |           |
|      |        |      |      | 1993–2002          |      | 2002–2011          |      | 2011–2015          |             | 1993–2015          |           |
| 18+  | SimSmoke | 3.2% | 2.8% | 13.6%              | 2.5% | 9.3%               | 2.4% | 3.3%               | 24.2%       |           |
|      | CPS-TUS | 3.1% | 2.3% | 27.1%              | 2.5% | 8.0%               | 2.6% | 6.5%               | 16.1%       |           |
|      |         |      |      | 95% CI (2.1, 2.4%) |      | (2.3, 2.6%)       |      | (2.5, 2.7%)       |             | (2.5, 2.7%)       |           |
| 18–24| SimSmoke | 4.9% | 3.6% | 26.9%              | 3.8% | 5.9%               | 3.8% | 0.5%               | 22.2%       |           |
|      | CPS-TUS | 5.0% | 1.8% | 63.5%              | 2.3% | 28.2%              | 2.9% | 24.0%              | 42.0%       |           |
|      |         |      |      | 95% CI (1.5, 2.2%) |      | (2.0, 2.8%)       |      | (2.5, 3.4%)       |             | (2.5, 3.4%)       |           |
| 25–34| SimSmoke | 4.1% | 3.9% | 4.5%               | 3.2% | 16.9%              | 3.3% | 3.2%               | 18.1%       |           |
|      | CPS-TUS | 4.2% | 3.6% | 14.2%              | 3.0% | 17.4%              | 3.0% | 3.1%               | 27.0%       |           |
|      |         |      |      | 95% CI (3.2, 3.9%) |      | (2.7, 3.3%)       |      | (2.8, 3.4%)       |             | (2.8, 3.4%)       |           |
| 35–54| SimSmoke | 2.3% | 2.5% | 4.8%               | 2.6% | 4.2%               | 2.4% | 5.0%               | 3.7%        |           |
|      | CPS-TUS | 2.3% | 2.2% | 4.1%               | 3.1% | 42.1%              | 3.4% | 9.4%               | 49.0%       |           |
|      |         |      |      | 95% CI (2.0, 2.4%) |      | (2.9, 3.3%)       |      | (3.2, 3.6%)       |             | (3.2, 3.6%)       |           |
| 55+  | SimSmoke | 2.7% | 2.0% | 25.6%              | 1.4% | 27.2%              | 1.4% | 6.0%               | 49.0%       |           |
|      | CPS-TUS | 2.7% | 1.8% | 36.0%              | 1.6% | 9.9%               | 1.7% | 9.5%               | 36.8%       |           |
|      |         |      |      | 95% CI (1.6, 1.9%) |      | (1.4, 1.7%)       |      | (1.6, 1.9%)       |             | (1.6, 1.9%)       |           |
25.7% (22.3%) to 14.9% (12.8%). The 2015 SimSmoke male (female) projected prevalence were outside the TUS 95% CI, but the relative reductions between 1993 and 2015 were 44.7% for males and 43.8% for females and were within 3% of the TUS estimates for both males (41.9%) and females (42.7%). By sub-periods, SimSmoke under-estimated the relative reduction in exclusive smoking from 1993 to 2002 less for females (–21.4% vs. –18.6%) than for males (–21.3 vs. -14.1%), did better for males (–23.5% vs –22.5%) than females (–22.5 vs. -21.1%) for 2002–2011, and underestimated the 2011–2013 reduction similarly for males (–8.2% vs. -12.6%) and females (–7.7% vs. -10.9%). In examining trends by age group, the biggest discrepancies were for 18–24 year olds, where SimSmoke over-predicted male and female reductions during the period 1993–2002, which was then reversed in 2002–2011 and 2011–2015.

Adult male (female) estimates from SimSmoke for dual use fell from 1.0% (0.05%) in 1993 to 0.7% (0.02%) in 2015, compared to TUS estimates of 0.05 (0.02). Compared to the TUS, the 2015 projections were within the 95% CI for females (falling from 0.5 to 0.2%), but outside the 95% CI for males. SimSmoke underestimated male reductions in 1993–2002 and over-predicted the reductions in 2002–2011 and 2011–2015, but underestimated female reductions for 1993–2002 and 2002–2011 and over-predicted for 2011–2015. Similar results were obtained for most age groups.

Male (female) exclusive SLT use estimated by SimSmoke fell from 3.2% (0.4%) in 1993 to 2.4% (0.1%) in 2015, yielding a 24% (71%) relative reduction between 1993 and 2015 compared to a 16% (77%) relative reduction in TUS. Female projections for 2015 were marginally within the 95% CI of the TUS, while the male SLT projection was just outside the 95% CI. SimSmoke underestimated male relative reduction for 1993–2002 and overestimated relative reductions for 2002–2011 and 2011–2015, while female relative reductions were underestimated in first two sub-periods and then reversed in 2011–2015. Discrepancies were particularly large in the 18–24 age group.

### The effect of policies implemented through 2017

Results comparing exclusive smoking, dual use and exclusive SLT prevalence projections with policies implemented between 1993 and 2017 to a counterfactual with policies set to their 1993 levels (i.e., the absence of policy change) are shown in Table 3. Results for tobacco-attributable deaths and lives saved are shown in Table 4, with the last column showing the summation over the years 1993–2067 to obtain the lives saved over that period.

In 1993, total tobacco-attributable deaths for males (females) were estimated as 226,979 (128,191), including 214,536 (125,607) exclusive smokers, 7072 (506) dual users and 5371 (2078) exclusive SLT users. For 2017, SimSmoke projected 251,180 (148,076) total attributable deaths and 187,870 (102,493) lives saved.
| Prevalence                        | Type  | 1993  | 2003  | 2017  | 2037  | 2067  | Relative Difference\(^a\) | 2017          | 2067          |
|----------------------------------|-------|-------|-------|-------|-------|-------|--------------------------|---------------|---------------|
| Male                             |       |       |       |       |       |       |                          |               |               |
| No policy change                 | Cigarette | 25.6% | 22.9% | 20.9% | 19.1% | 18.6% | –                         | –             | –             |
|                                   | Dual   | 1.05% | 1.02% | 1.02% | 0.96% | 0.93% | –                         | –             | –             |
|                                   | SLT    | 3.19% | 3.00% | 2.86% | 2.68% | 2.60% | –                         | –             | –             |
| Actual/ status quo               | Cigarette | 25.6% | 19.6% | 13.6% | 10.5% | 9.6%  | –34.8%                    | –48.3%        |               |
|                                   | Dual   | 1.05% | 0.88% | 0.68% | 0.57% | 0.52% | –32.5%                    | –43.6%        |               |
|                                   | SLT    | 3.19% | 2.71% | 2.38% | 2.14% | 2.03% | –16.5%                    | –21.9%        |               |
| Price alone                      | Cigarette | 25.6% | 20.3% | 15.8% | 12.7% | 11.7% | –24.5%                    | –37.1%        |               |
|                                   | Dual   | 1.05% | 0.91% | 0.78% | 0.67% | 0.62% | –23.1%                    | –33.3%        |               |
|                                   | SLT    | 3.19% | 3.00% | 2.86% | 2.68% | 2.60% | –5.1%                     | –15.8%        |               |
| Smoke-free air law alone         | Cigarette | 25.6% | 22.8% | 20.0% | 17.9% | 17.3% | –4.0%                     | –7.1%         |               |
|                                   | Dual   | 1.05% | 1.02% | 0.98% | 0.90% | 0.87% | –3.9%                     | –6.4%         |               |
|                                   | SLT    | 3.19% | 3.00% | 2.86% | 2.70% | 2.62% | 0.3%                      | 0.8%          |               |
| Media campaigns alone            | Cigarette | 25.6% | 22.8% | 20.8% | 18.9% | 18.4% | –0.6%                     | –0.8%         |               |
|                                   | Dual   | 1.05% | 1.02% | 1.01% | 0.95% | 0.92% | –0.5%                     | –0.7%         |               |
|                                   | SLT    | 3.19% | 2.99% | 2.85% | 2.68% | 2.59% | –0.2%                     | –0.3%         |               |
| Cessation treatment alone        | Cigarette | 25.6% | 22.6% | 20.2% | 18.3% | 17.8% | –3.4%                     | –4.2%         |               |
|                                   | Dual   | 1.05% | 1.01% | 0.98% | 0.92% | 0.89% | –3.0%                     | –3.8%         |               |
|                                   | SLT    | 3.19% | 2.98% | 2.81% | 2.62% | 2.54% | –1.6%                     | –2.3%         |               |
| Health warning alone             | Cigarette | 25.6% | 22.9% | 20.9% | 19.1% | 18.6% | 0.0%                      | 0.0%          |               |
|                                   | Dual   | 1.05% | 1.02% | 1.02% | 0.96% | 0.93% | 0.0%                      | 0.0%          |               |
|                                   | SLT    | 3.19% | 3.00% | 2.82% | 2.64% | 2.55% | –1.1%                     | –1.7%         |               |
| Advertising ban alone            | Cigarette | 25.6% | 22.9% | 20.8% | 18.9% | 18.4% | –0.5%                     | –0.9%         |               |
|                                   | Dual   | 1.05% | 1.02% | 1.01% | 0.95% | 0.92% | –0.5%                     | –0.8%         |               |
|                                   | SLT    | 3.19% | 3.00% | 2.84% | 2.67% | 2.58% | –0.4%                     | –0.8%         |               |
| Youth access alone               | Cigarette | 25.6% | 22.8% | 20.5% | 18.3% | 17.7% | –2.0%                     | –4.9%         |               |
|                                   | Dual   | 1.05% | 1.02% | 1.00% | 0.93% | 0.90% | –1.2%                     | –3.0%         |               |
|                                   | SLT    | 3.19% | 3.00% | 2.86% | 2.69% | 2.60% | 0.0%                      | 0.0%          |               |
| Female                           | Cigarette | 22.1% | 19.7% | 18.4% | 17.1% | 16.8% | –                        | –             |               |
|                                   | Dual   | 0.05% | 0.03% | 0.03% | 0.02% | 0.02% | –                         | –             |               |
|                                   | SLT    | 0.38% | 0.22% | 0.12% | 0.08% | 0.07% | –                         | –             |               |
| Actual/ status quo               | Cigarette | 22.1% | 16.9% | 11.9% | 9.3%  | 8.4%  | –35.2%                    | –49.9%        |               |
|                                   | Dual   | 0.05% | 0.03% | 0.02% | 0.01% | 0.01% | –32.5%                    | –47.0%        |               |
|                                   | SLT    | 0.38% | 0.20% | 0.10% | 0.07% | 0.06% | –16.4%                    | –20.7%        |               |
| Price alone                      | Cigarette | 22.1% | 17.5% | 13.9% | 11.3% | 10.4% | –24.6%                    | –38.0%        |               |
|                                   | Dual   | 0.05% | 0.03% | 0.02% | 0.01% | 0.01% | –21.8%                    | –35.9%        |               |
|                                   | SLT    | 0.38% | 0.21% | 0.11% | 0.07% | 0.06% | –11.7%                    | –15.8%        |               |
| Smoke-free air law alone         | Cigarette | 22.1% | 19.6% | 17.7% | 16.0% | 15.6% | –4.1%                     | –7.4%         |               |
|                                   | Dual   | 0.05% | 0.03% | 0.02% | 0.01% | 0.02% | –3.9%                     | –6.8%         |               |
|                                   | SLT    | 0.38% | 0.22% | 0.12% | 0.08% | 0.07% | 0.2%                      | 1.1%          |               |
| Media campaign alone             | Cigarette | 22.1% | 19.6% | 18.3% | 17.0% | 16.7% | –0.6%                     | –0.8%         |               |
deaths, including 238,852 (146,076) exclusive smokers, 7085 (364) dual users and 5243 (969) exclusive SLT users. Since 1993, premature deaths generally grew and then declined in number, except among female dual and exclusive SLT users which showed continuous decline.

With no new policies implemented after 1993, SimSmoke projected that exclusive cigarette, dual and exclusive SLT use rates would have been 35, 32.5 and 16.5% higher respectively in 2017 for males, with similar relative differences for females. As a result of policies, annual tobacco-attributable deaths for males (females) were reduced by 34,800 (21,679) in 2017 alone with a cumulative impact of 268,628 (167,308) fewer tobacco-attributable deaths from 1993 to 2017. By 2067, the relative reductions for males (females) increased to 48% (50%) for exclusive cigarette, 44% (47%) for dual and 22% (21%) for exclusive SLT users, as policies continued to reduce tobacco use through increased cessation and reduced initiation. Due to policies implemented between 1993 and 2017, SimSmoke projected a total of 4,595,461 (2,939,392) premature deaths averted by 2067.

Comparing the counterfactual for individual policies, much of the reduction in exclusive cigarette use was due to price increases. Price increases alone were predicted to reduce male (female) exclusive cigarette use rates in relative terms by 25% (25%) in 2017 and by 37% (38%) in 2067, and to have averted 3,128,890 (1,959,661) male (female) deaths in total by 2067. Smoke-free air laws yielded a 4% relative reduction in exclusive cigarette use in 2017, which increased to a 7% reduction by 2067. Cessation treatments and youth access enforcement showed 3–4 and 2% relative reductions respectively in 2017 increasing to 4–5 and 5% by 2067. Mass media campaigns and advertising bans showed 0.6 and 0.5% relative reductions respectively in 2017 increasing to 0.8 and 0.9% reductions by 2067. For exclusive cigarettes, taxes represented 71% of the total policy effects, followed by smoke-free air laws at 11%, and cessation treatment at 10% by 2017.

Similar but slightly smaller relative reductions were projected for dual use. However, much smaller effects were projected for exclusive SLT use, where the largest relative reductions by 2067 for males (females) were 13% (12%) for prices, followed by 1.6% (2.5%) for cessation treatment and 1.1% (1.2%) for health warnings. Some categories show increased exclusive SLT use in future years, due to the larger pool of potential initiates from those who would have smoked cigarettes.

### Discussion
Our estimates of the increase in exclusive cigarette use between 1993 and 2015 from US SimSmoke generally validated well against trends found in the large scale, nationally representative TUS. However, SimSmoke over-estimated reductions among male smokers for most ages, especially those 18–24, until 2002, while under-estimating reductions in later years. By 2015, SimSmoke female projections of adult exclusive and dual cigarette use were close to TUS estimates, while male reductions were under-estimated for dual use but over-estimated for exclusive SLT use. The deviations for dual use may reflect the relatively small number of such
### Table 4: Tobacco-Attributable Deaths by Smoking Status Projected by SimSmoke under Multiple Scenarios for Males and Females, 1993–2067

| Policies                     | Type     | 1993  | 2003  | 2017  | 2037  | 2067  | Cumulative   | Cumulative   |
|------------------------------|----------|-------|-------|-------|-------|-------|--------------|--------------|
|                              |          |       |       |       |       |       | 1993–2017    | 1993–2067    |
| Male Tobacco-Attributable Deaths with Policies |          |       |       |       |       |       |              |              |
| Actual/ status quo           | Cigarette| 214,536| 235,471| 238,852| 200,634| 144,977| 5,850,036    | 15,175,074   |
|                              | Dual     | 7072  | 6755  | 7085  | 8195  | 6859  | 172,098      | 550,611      |
|                              | SLT      | 5371  | 5898  | 5243  | 5368  | 5321  | 141,452      | 406,886      |
|                              | Total    | 226,979| 248,123| 251,180| 214,196| 157,158| 6,163,585    | 16,132,572   |
| Lives Saved Compared to the Counterfactual of No Policy Changeb |          |       |       |       |       |       |              |              |
| Actual/ status quo           | Cigarette| –     | 4167  | 33,407| 71,464| 128,514| 257,655      | 4,350,888    |
|                              | Dual     | –     | 126   | 1011  | 3141  | 5747  | 7520         | 186,594      |
|                              | SLT      | –     | 68    | 381   | 949   | 1700  | 3453         | 57,979       |
|                              | Total    | –     | 4362  | 34,800| 75,553| 135,961| 268,628      | 4,595,461    |
| Price alone                  | Cigarette| –     | 3058  | 20,160| 45,179| 96,264| 162,609      | 2,959,865    |
|                              | Dual     | –     | 92    | 600   | 1962  | 4278  | 4644         | 126,743      |
|                              | SLT      | –     | 60    | 282   | 659   | 1288  | 2759         | 42,282       |
|                              | Total    | –     | 3210  | 21,042| 47,801| 101,831| 170,013      | 3,128,890    |
| Smoke-free air law alone     | Cigarette| –     | 48    | 2288  | 9212  | 18,973| 12,291       | 549,538      |
|                              | Dual     | –     | 0     | 0     | 0     | 0     | 0            | 0            |
|                              | SLT      | –     | 1     | 74    | 412   | 843   | 386          | 24,265       |
|                              | Total    | –     | 49    | 2362  | 9623  | 19,816| 12,677       | 573,445      |
| Media campaign alone         | Cigarette| –     | 42    | 573   | 1182  | 2252  | 4033         | 75,506       |
|                              | Dual     | –     | 1     | 18    | 52    | 98    | 118          | 3234         |
|                              | SLT      | –     | 0     | 3     | 10    | 22    | 21           | 667          |
|                              | Total    | –     | 43    | 594   | 1245  | 2373  | 4172         | 79,406       |
| Cessation treatment alone    | Cigarette| –     | 328   | 5801  | 13,195| 16,515| 38,207       | 693,120      |
|                              | Dual     | –     | 9     | 174   | 596   | 773   | 1098         | 30,665       |
|                              | SLT      | –     | 2     | 50    | 173   | 266   | 308          | 9589         |
|                              | Total    | –     | 339   | 6025  | 13,963| 17,554| 39,613       | 733,373      |
| Health warning alone         | Cigarette| –     | 0     | 0     | 0     | 0     | 0            | 0            |
|                              | Dual     | –     | 0     | 0     | 0     | 0     | 0            | 0            |
|                              | SLT      | –     | 0     | 17    | 73    | 134   | 85           | 4166         |
|                              | Total    | –     | 0     | 17    | 73    | 134   | 85           | 3596         |
| Advertising ban alone        | Cigarette| –     | 0     | 319   | 1069  | 2123  | 1205         | 62,167       |
|                              | Dual     | –     | 0     | 11    | 47    | 93    | 42           | 2703         |
|                              | SLT      | –     | 0     | 5     | 21    | 47    | 27           | 1296         |
|                              | Total    | –     | 0     | 335   | 1137  | 2263  | 1274         | 66,165       |
| Youth access alone           | Cigarette| –     | 0     | 17    | 1824  | 10,683| 26           | 189,846      |
|                              | Dual     | –     | 0     | 1     | 63    | 348   | 1            | 6343         |
|                              | SLT      | –     | 0     | 0     | 1     | 1     | 0            | 44           |
|                              | Total    | –     | 0     | 18    | 1887  | 11,032| 27           | 196,232      |

| Policies                     | Type     | 1993  | 2003  | 2017  | 2037  | 2067  | Cumulative   |
|------------------------------|----------|-------|-------|-------|-------|-------|--------------|
|                              |          |       |       |       |       |       | 1993–2017    |
| Female Tobacco-Attributable Deaths with Policies |          |       |       |       |       |       |              |
| Actual/ status quo           | Cigarette| 125,607| 140,968| 146,742| 142,518| 102,473| 3,508,793    |
|                              | Dual     | 7072  | 6755  | 7085  | 8195  | 6859  | 172,098      |
|                              | SLT      | 5371  | 5898  | 5243  | 5368  | 5321  | 141,452      |
|                              | Total    | 226,979| 248,123| 251,180| 214,196| 157,158| 6,163,585    | 16,132,572   |

b The lives saved estimates are calculated: (counterfactual with the policy change – counterfactual with the status quo policy)/2.
Contrary to the results for exclusive cigarette use, both male exclusive SLT use and male dual use underestimated the reductions for 1993–2002, while moving closer to the TUS estimates by 2015. These reversals were particularly apparent for the 18–24 and 35–54 age groups.

Consistent with previous literature [8, 9], the model projected that overall SLT rates fell quite rapidly for both dual and exclusive SLT use through 2002, but decelerated in recent years. However, SimSmoke under-predicted the decline through 2002. While some policies were directed at SLT use between 1993 and Table 4 Tobacco-Attributable Deaths by Smoking Status Projected by SimSmoke under Multiple Scenarios for Males and Females, 1993–2067 (Continued)

| Policies                        | Type       | 1993  | 2003  | 2017  | 2037  | 2067  | Cumulative |
|--------------------------------|------------|-------|-------|-------|-------|-------|------------|
|                                |            |       |       |       |       |       |            |
|                                | Dual       | 506   | 443   | 364   | 221   | 103   | 10,857     | 20,938     |
|                                | SLT        | 2078  | 1863  | 969   | 353   | 173   | 41,759     | 60,235     |
|                                | Total      | 128,191 | 143,275 | 148,076 | 143,093 | 102,749 | 3,561,410 | 10,042,508 |
| Lives Saved Compared to the Counterfactual of No Policy Changea | Cigarette  | –     | 2617  | 21,559 | 48,462 | 90,074 | 165,934    | 2,932,063  |
|                                | Dual       | –     | 10    | 48    | 63    | 91    | 436        | 3845       |
|                                | SLT        | –     | 27    | 72    | 49    | 46    | 938        | 3484       |
|                                | Total      | –     | 2653  | 21,679 | 48,574 | 90,212 | 167,308    | 2,939,392  |
|                                | Cigarette  | –     | 1936  | 13,098 | 29,304 | 67,050 | 106,278    | 1,954,695  |
|                                | Dual       | –     | 7     | 28    | 36    | 68    | 275        | 2462       |
|                                | SLT        | –     | 23    | 51    | 32    | 34    | 751        | 2504       |
|                                | Total      | –     | 1967  | 13,178 | 29,372 | 67,152 | 107,304    | 1,959,661  |
|                                | Cigarette  | –     | 28    | 1393  | 6274  | 13,254 | 7360       | 369,202    |
|                                | Dual       | –     | 0     | 0     | 0     | 0     | 0          | 0          |
|                                | SLT        | –     | 0     | 3     | 8     | 13    | 451        | 33         |
|                                | Total      | –     | 29    | 1396  | 6282  | 13,267 | 7378       | 369,639    |
|                                | Cigarette  | –     | 24    | 353   | 798   | 1564  | 2434       | 51,313     |
|                                | Dual       | –     | 0     | 1     | 1     | 2     | 5          | 52         |
|                                | SLT        | –     | 0     | 0     | 1     | 1     | 5          | 33         |
|                                | Total      | –     | 24    | 354   | 800   | 1655  | 2645       | 51,411     |
|                                | Cigarette  | –     | 201   | 3676  | 9978  | 12,899 | 23,840     | 513,312    |
|                                | Dual       | –     | 1     | 9     | 14    | 13    | 62         | 717        |
|                                | SLT        | –     | 1     | 10    | 10    | 8     | 81         | 572        |
|                                | Total      | –     | 202   | 3695  | 10,003 | 12,920 | 23,983     | 514,601    |
|                                | Cigarette  | –     | 0     | 0     | 0     | 0     | 0          | 0          |
|                                | Dual       | –     | 0     | 0     | 0     | 0     | 0          | 0          |
|                                | SLT        | –     | 0     | 4     | 4     | 4     | 23         | 218        |
|                                | Total      | –     | 0     | 4     | 4     | 4     | 23         | 211        |
|                                | Cigarette  | –     | 0     | 195   | 735   | 1472  | 724        | 41,862     |
|                                | Dual       | –     | 0     | 0     | 1     | 1     | 2          | 51         |
|                                | SLT        | –     | 0     | 1     | 1     | 1     | 7          | 64         |
|                                | Total      | –     | 0     | 197   | 738   | 1475  | 734        | 41,977     |
|                                | Cigarette  | –     | 0     | 7     | 822   | 6598  | 11         | 103,780    |
|                                | Dual       | –     | 0     | 0     | 1     | 6     | 0          | 100        |
|                                | SLT        | –     | 0     | 0     | 0     | 0     | 0          | 0          |
|                                | Total      | –     | 0     | 7     | 823   | 6604  | 11         | 103,880    |

*a Lives saved were calculated as the difference in projected deaths with the policy implemented and with no policy implemented
2002, most were directed at cigarette use, including tax increases, smoke-free air laws, and media campaigns. These policies may have also reduced SLT use, suggesting the importance of strong cigarette policies in reducing overall tobacco use. The model fails to predict well the increasing pattern of exclusive SLT and dual use found in recent TUS surveys and in recent studies [6, 10, 11, 82, 83]. The failure to predict these changes in trend may reflect the changing composition of the SLT industry. Reynolds American acquired Conwood Smokeless Tobacco Company in 2006 and soon thereafter introduced Camel Snus, and Altria acquired the U.S. Smokeless Tobacco Company in 2009 and began marketing Marlboro Snus. Together they controlled 85% of the market [13]. Industry documents [84, 85] indicate that cigarette companies began promoting SLT products as a way for smokers to satisfy nicotine cravings in places where smoking is banned, and marketing expenditures, including those on price promotions [86] and flavored products [87, 88], increased. The largest increases in SLT use were among young adults, possibly reflecting marketing targeted toward this age group. Policies may need to be directed at this age group in order to reduce SLT and dual use. SimSmoke projected that policies implemented between 1993 and 2017 reduced cigarette use by about 35% and SLT use by 16.5%. Consistent with earlier SimSmoke analyses [89, 90], the largest percentage reductions in cigarette and SLT use and in attributable deaths were due to taxes. Smoke-free air laws were next most important for cigarettes, while cessation treatment was next most important for SLTs. The importance of taxes and smoke-free air laws has also been found in previous US SimSmoke models of cigarette use [2, 20–22, 25, 26]. SimSmoke also provided estimates of the health effects of SLT use. SimSmoke estimated 6212 deaths attributable to exclusive SLT use in 2017 (down from 7449 in 1993), but projected general increases in future years. However, we treated SLT as a homogeneous category in terms of risks, potentially overestimating risks (e.g., SLT users switching to snus) [91–95]. The number of SLT-attributable deaths paled in comparison to the total deaths attributable to dual and exclusive cigarette use, which were estimated as 7449 and 385,594 respectively in 2017. The model did not distinguish the relative risks of dual use from that of exclusive cigarette use, although dual use may reduce the number of cigarettes smoked over a lifetime and, thereby, reduce mortality risks. Like all models, SimSmoke estimates are only as strong as the assumptions and underlying data. In particular, the projections of cigarette use were based on initiation and cessation rates derived in 1993 subject to policy changes over time. Cessation rates for exclusive SLT users were not available, and we were not able to distinguish cessation rates for dual as compared to exclusive cigarette use. In addition, the effect sizes of policies on SLT use that we used in SimSmoke, are tentative, largely reflecting studies prior to 2007 [17]. Better information is needed on policy effectiveness, especially for recent years since the cigarette companies came to dominate the industry, and on the extent to which policies, such as media campaigns, are directed at SLT use. Better information is also needed about the timing of policies effects and the potential synergies or overlapping effects of policies as they relate to cigarette and SLT use. Another limitation is that SimSmoke considers only cigarette and SLT use, and does not include the use of other nicotine delivery products, such as cigars, water pipes and e-cigarettes, that may substitute or complement the use of cigarettes and SLT. Growth in e-cigarette use between 2011 and 2015 [96, 97] may explain the rapid reduction in cigarette use and the slowing growth of SLT use.

Conclusions

While the landscape for nicotine delivery products has dramatically changed in the last 10 years, some lessons can be gleaned from the modeling in this paper. With cigarettes still being the dominant form of nicotine delivery, cigarette-oriented policies may be an effective means, perhaps the most effective means, of reducing SLT use and possibly reducing the use of other nicotine delivery products, such as e-cigarettes. Policies directed at SLT use, especially those that affect youth and young adults, may also play a role but it should be recognized that substitution of exclusive SLT use (which is relatively low risk) for cigarette use can reduce overall harms. In developing a coherent policy approach, it will be important to monitor the use of other products, such as cigars and e-cigarettes. In addition, it will be important to monitor the marketing and pricing policies of cigarette companies, which have strong incentives to protect the high profit margins of cigarettes.

Abbreviations

FSPTCA: Smoking Prevention and Tobacco Control Act; SLT: smokeless tobacco

Acknowledgements

We would like to thank Frank Chaloupka and Raymond Boyle for comments on a previous draft of this paper.

Funding

Funding was received from the Food and Drug Administration through the National Institute on Drug Abuse, National Institute of Health, under grant R01DA036497. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data in the writing of the manuscript, and in the decision to publish the results.

Availability of data and materials

The datasets used during the current study are publicly available and the formats used in this study are available from the corresponding author on reasonable request.
Authors’ contributions
DTL conceived of the idea, wrote the initial draft, and revised the paper, while ZY and YL helped in developing the analysis, conducted the data analyses, wrote the initial methods and results section, and reviewed the final manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate
Not applicable. All data is publicly available.

Competing interests
The authors declare that they have no competing interests.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Received: 31 October 2017 Accepted: 24 May 2018
Published online: 05 June 2018

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