Limiting youth access to tobacco: Comparing the long-term health impacts of increasing cigarette excise taxes and raising the legal smoking age to 21 in the United States

Sajjad Ahmad a,∗, John Billimek b,1

a Department of Civil, Architectural and Environmental Engineering, University of Miami, 1251 Memorial Drive, Coral Gables, FL 33146-0630, United States
b Department of Psychology and Social Behavior, University of California, Irvine, 3340 Social Ecology II, Irvine, CA 92697, United States

Abstract

Although many states in the US have raised cigarette excise taxes in recent years, the size of these increases have been fairly modest (resulting in a 15% increase in the per pack purchase price), and their impact on adult smoking prevalence is likely insufficient to meet Healthy People 2010 objectives. This paper presents the results of a 75-year dynamic simulation model comparing the long-term health benefits to society of various levels of tax increase to a viable alternative: limiting youth access to cigarettes by raising the legal purchase age to 21. If youth smoking initiation is delayed as assumed in the model, increasing the smoking age would have a minimal immediate effect on adult smoking prevalence and population health, but would affect a large drop in youth smoking prevalence from 22% to under 9% for the 15–17-year-old age group in 7 years (by 2010)—better than the result of raising taxes to increase the purchase price of cigarettes by 100%. Reducing youth initiation by enforcing a higher smoking age would reduce adult smoking prevalence in the long-term (75 years in the future) to 13.6% (comparable to a 40% tax-induced price increase), and would produce a cumulative gain of 109 million QALYs (comparable to a 20% price increase). If the political climate continues to favor only moderate cigarette excise tax increases, raising the smoking age should be considered to reduce the health burden of smoking on society. The health benefits of large tax increases, however, would be greater and would accrue faster than raising the minimum legal purchase age for cigarettes.

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Keywords: Legal smoking age; Tobacco taxes; Youth smoking; System dynamics; Simulation; QALYs; Smoking prevalence; Policy

1. Introduction

Although the United States has seen considerable declines in tobacco use in recent years, adult smoking prevalence at the end of this decade is likely to remain significantly above the target established with Healthy
People 2010 [1,2]. To meet this objective target, adult prevalence (which has fallen from 25% in 1995 to 23% in 2001 [3] must drop to 12% [4]. Considering the effects of tobacco use on mortality, productivity, birth outcomes and quality of life, delayed attainment of smoking rate targets carries significant public health consequences.

Among the best-supported interventions to reduce smoking in the population are increased cigarette excise taxes [5–9]. Popular because they are believed to simultaneously discourage smoking initiation and encourage cessation while increasing state revenues [5,9], new excise tax increases have been passed in 35 states and the District of Columbia since the beginning of 2002. Because the smoking behavior of teenagers, who are the most vulnerable to initiate smoking, is particularly sensitive to price increases, the incremental annual benefit of raising taxes grows with every year for decades [9,10].

In spite of strong evidence for the effectiveness of cigarette taxes to reduce smoking, there may be limits to how high a tax rate will be politically viable. Recent tax increases, although frequent, have been modest in most states, resulting in an average per pack price increase of only about 15%, and in several cases are only temporary [11]. Resistance from tobacco companies and smokers [5] coupled with concerns about the possible emergence of black markets [12] and an unfair burden on poor smokers who may lack the resources to quit [13] may discourage lawmakers from setting tax rates high enough to derive maximum benefit to the population.

Keeping in mind the political costs of additional tax increases, policymakers may want to consider other interventions to improve the population’s progress toward healthy people smoking prevalence goals. Already, many states have implemented programs including education and advertising campaigns, clean indoor air laws and telephone support hotlines, but a weakness in current efforts to reduce smoking is the relative ease of youth access to tobacco, which persists even with stricter enforcement of the current legal smoking age [14].

Teenagers obtain cigarettes from two primary types of sources: commercial sources (direct retail purchase), and social sources (buying or being given cigarettes from friends, acquaintances and relatives). With more rigorous enforcement of the minimum legal purchase age for tobacco of 18 years, the proportion of underage smokers who usually buy their own cigarettes in stores has been cut in half (from 38.7% to 18.8%) from 1995 to 2003. This reduction in reliance on commercial sources of cigarettes, however, has been offset in part by increased use of social sources over the same time span. The proportion of teen smokers who usually obtain cigarettes by giving someone else money to buy them has nearly doubled (from 16% in 1995 to 30% in 2003) and 9% of underage smokers are usually simply given cigarettes by adults [15].

Gaps in youth access restrictions are problematic because they undermine the potentially large health benefits of reduced youth prevalence. By one estimate, the long-term population health benefits of a given decrease in youth smoking initiation probability are seven times greater than those resulting from comparable improvements in adult cessation probability [16]. Ninety percent of current adult smokers took up the habit before their 18th birthday [17], and more than half of those who initiate smoking in their teens continue to smoke for 16 years or longer [18]. If youth access to tobacco can be restricted, it will provide direct health benefits to those who will not initiate smoking. It will also benefit those for whom initiation will be simply delayed because of the increased probability of cessation associated with a later age of onset [19].

Effectiveness of youth access tobacco programs, however, has been debated in literature. Rigotti et al. [20] reporting on an evaluation of the effectiveness of enforcing laws that ban tobacco sales to minors as a strategy to reduce tobacco use by adolescents conclude, “we found no meaningful difference in smoking behavior between communities that implemented enforcement programs and those that did not.” Later, in response to comments by Moskowitz et al. [21] the authors acknowledge [22] “nonetheless, we remain optimistic that vigorous enforcement of the law is possible and can stop the illegal sale of tobacco to children.”

In a meta-analysis study, Fichtenberg and Glantz [22] argue that youth access tobacco programs do not affect teen smoking prevalence because as fewer merchants sell tobacco to minors, teens will use social sources to obtain tobacco. In an editorial, based on results from Fichtenberg and Glantz study, Ling et al. [23] conclude that it is time to abandon youth access tobacco programs. This resulted in additional discus-
sion [24] and a rebuttal from authors [25]. In the discussion, DiFranza raised questions about the method used in the Fichtenberg and Glantz study, and noted that the meta-analysis improperly combined studies of different cohort, cross section, and controlled and non-controlled interventions from three different countries. In a letter to editor, Jason et al. [26] review their position and admit that it is premature to abandon youth access to tobacco programs.

In their discussion of flaws in current youth access restrictions, DiFranza and Coleman [14] suggest that a key step to improving the system would be to raise the minimum legal purchase age (MLPA) for tobacco to 21. Ahmad [27,28] has presented a cost-effectiveness analysis of raising the legal smoking age to 21 in California and the US.

The legal smoking age in most of the States in USA is 18. Alaska, Alabama and Utah have minimum smoking age of 19; Illinois [29] and Massachusetts [30] are increasing the age to 19. Several states including Maine [31], California [32], Connecticut [33], New Jersey [34], New York [35], North Dakota [36], Oregon [37], South Carolina [38], Texas [39], and Vermont [40] have considered (through legislative bills in State assembly) increasing the legal smoking age. The measure carries a significant popular support across party lines in opinion polls [41,42].

The greatest benefit of a higher MLPA, given the increased importance of non-retail sources of cigarettes, might be the reduction of youth access through social sources. DiFranza and Coleman [14] cite a previously unpublished survey by Radeki indicating that 90% of adults approached by minors to buy cigarettes are under 21. Although minors routinely encounter 18-year olds at school and elsewhere, they typically have much less contact with 21-year olds in their social circles. There is no direct evidence to indicate raising the smoking age will impact smoking rates at all, but it is plausible such a policy change might significantly reduce minors’ access to individuals who can legally purchase tobacco.

Combined with rigorous vendor compliance checks, raising the smoking age has the potential to further limit teens’ commercial access to cigarettes by reducing cashiers’ ambiguity in determining if a customer is of legal age to buy tobacco. As it is, teenagers who appear older than 16 have a significantly greater success rate in purchase attempts compared to younger-looking individuals. Even if many 19- and 20-year olds succeed in buying cigarettes following the enactment of an MLPA of 21, more individuals under 18 may be clearly recognized as being underage and, therefore, may have their access better controlled. Given the high risk for adult smoking associated with initiation before age 18 [17,18], delaying access in this way may carry a significant impact on future smoking behavior. If this is true, as predicted for tax increases, the benefits of improved youth access restriction would grow with each passing year as more adolescents enter adulthood as non-smokers [9,10]. The tobacco industry, restricted from overtly targeting adolescents, appears to be focusing on young adults [43]. Raising the MLPA could also curb some of these tobacco company efforts with this age group and may help offset the recent rise in initiation rates among young adults.

This paper provides a comparison of the health benefits that would accumulate for the U.S. population following the enactment of age 21 as the new MLPA, and compares them to the predicted short- and long-term impacts of various levels of excise tax increases. First, we provide an overview of the development and calibration of the dynamic simulation model used to estimate the short- and long-term outcomes of the indicated policy changes. Second, we describe the key outcomes estimated in the simulation, and discuss our assumptions of how the various policy interventions will affect initiation and cessation rates in the population in terms of price elasticity for tax increases, and youth initiation rates for raising the smoking age. Next, we present estimates from the model of the cumulative health impacts, i.e., quality-adjusted life years of each intervention in both short term (2010) and long term (2078, i.e., after 75 years), and finally we discuss the results and present some caveats to consider when interpreting them.

2. Methods

Levy et al. [44–46] have done extensive work on estimating the effects of policies directed at youth access, using a simulation modeling approach. We developed a dynamic simulation model using Vensim [47] to estimate the population health outcomes resulting from raising taxes on cigarettes and raising the
legal smoking age to 21. This model has been widely use to explore several tobacco control policies and is described in more detail elsewhere [9,27,28,48–50].

2.1. Model overview

The simulated population is initialized to reflect the size and smoking status distribution of every age cohort by gender for the 2003 United States population [15,51–53]. Then, using change probabilities derived from external sources, the simulation uses a state-transition model with a time step of 1 year to predict births, deaths, aging, net migration and changes in smoking status over the next 75 years. A period of 75 years was selected to ensure that the full cumulative lifetime impact of each simulated policy scenario is captured in the output.

Change probabilities vary based on the characteristics of members of the population for any given year. The number of live births for a given year in the simulation is computed by multiplying the number of women in each age cohort by its respective age-specific fertility rate [54]. Similarly, the number of deaths is computed by multiplying the number of people of each combination of age, gender and smoking status by that group’s respective mortality probability [54,55], and taking the sum across all groups for each year. Net migration rates reflect age and gender specific changes due to people moving in an out of the population [54,56].

Participation in smoking behavior is captured in three smoking status categories: never smokers (smoked less than 100 cigarettes in lifetime), current smokers (smoked 100 or more cigarettes in lifetime and has smoked in past 30 days), and former smokers (smoked 100 or more cigarettes in lifetime, but none in the past 30 days). The initial population is divided into these three smoking status categories according to external prevalence estimates [15,53,57]. In each subsequent year, the current number of never smokers within each age by gender group is multiplied by age- and gender-specific initiation probabilities to determine how many people leave the never smoker category to join the current smoker category. The number of current smokers (by age and gender group) is multiplied by group-specific cessation probabilities to give the number of individuals subtracted from the current smoker category. The number of former smokers (by age and gender group) is multiplied by group-specific relapse probability to indicate how many former smokers will become current smokers again. Age- and gender-specific initiation, cessation and relapse probabilities were derived from multiple sources [52,58,59]. Cessation probability estimates were adjusted based on age of smoking initiation to reflect the increased likelihood of cessation that accompanies a later age of smoking onset.

2.2. Model calibration

The model’s accuracy was improved through an iterative calibration process for which the model is initiated with actual 1995 population values and run to a future time point. The output is then compared to external estimates of (i) total population size (by age and gender) [51], (ii) current adult smoker prevalence [2], and (iii) life expectancy (by age, gender and smoking status) [60,61]. Between iterations, some change probabilities were adjusted until the model produced results very similar to external estimates of total population in year 2025, 2050 and 2075 (within 1% for all groups). Model estimates also closely matched externally computed values of adult smoking prevalence for 2003 (22.3% from the model compared to 22.5% from external estimate) and life expectancies (for example, in the model, a 45-year-old female current smoker would live an average of 33.94 additional years—very close to the external life expectancy estimate of 33.89 years from actuarial data).

2.3. Key outcomes

Smoking prevalence for adults (18 years and older) is calculated for every year of the simulation run as the ratio of the number of current smokers aged 18 or older and the total population of that age group. Because no estimates of price elasticity for smoking participation were available for youths aged 14 and younger, our annual estimates of youth smoking prevalence only include the ratio of the number of smokers aged 15–17 and the total number of people in that age group.

Health outcomes are quantified both in terms of total accumulated life years (the cumulative sum across the simulation period of the total number of living members of the population at the end of each year) and, as recommended by the US Task Force on Cost-Effectiveness in
Health and Medicine [62], quality-adjusted life years (QALYs).

The QALY combines improvements in length of life and health-related quality of life into a single measure by adjusting each life year that accrues according to a quality of life (QOL) score. For example, 10 years of life at 85% quality would result in 8.5 QALYs. In our model, each year of life represented was adjusted by assigning a QOL score based on the individual’s age, gender and smoking status. These QOL scores were summed for the whole population for every year of the model to determine the number of QALYs that accumulated that year, and these annual totals were summed across the entire simulation period. We used QOL scores derived from Quality of Well Being scale data provided by a 1999 personal communication from Kaplan. Because we are not comparing present day costs to future benefits, we did not apply a discount rate to any outcome values.

2.4. Scenarios simulated

To determine the public health benefit resulting from each of the proposed policy interventions, we first ran the simulation assuming no policy change (that is, no change in smoking prevalence across the model run) to produce results for a status quo base case. Then, we completed additional simulation runs incorporating assumptions about how each proposed policy change would effect initiation, cessation and relapse probabilities across the population, and compared those results to the status quo case to determine the incremental health benefit of each intervention.

2.4.1. Raising cigarette taxes

Modeling the impacts of tax increases on smoking behavior required us to estimate price elasticity (that is, the amount of change in behavior predicted per unit change in price). Consistent with other work [7,63] and building on our previous work [9], we estimated age group-specific price elasticity of smoking participation with a weighted ordinary least squares model using a standard model of consumption.

The elasticity estimation model takes smoking behavior and demographic data for over 1 million observations from the Centers for Disease Control and Prevention Behavioral Risk Factor Surveillance Systems (BRFSS) [53] from all 50 states from 1993 to 2000 (except 1993 when Wyoming did not participate) and merges it with state-specific cigarette tax and price data [64]. A dichotomous dependent variable indicating whether each individual is a current smoker was then regressed against state-specific cigarette price, various socioeconomic and demographic covariates (including gender, health status, age, race, education, marital status, and income), and dummy variables for state and year to determine age-specific price elasticity for adults. Because the BRFSS does not include minors, we used price elasticity estimates for the 15–17 age group from other studies. Harris and Chan [7] and Tauras and Chaloupka [65] have estimated overall price elasticity for youth as $-0.831$ and $-0.79$, respectively. Unlike our price elasticity estimates, these estimates capture both participation changes and reduced consumption. Because our model only addresses participation changes, based on evidence from literature, we estimated that 50% of the adolescent price elasticity was due to reduced prevalence, which resulted in a participation elasticity estimate of $-0.4155$ from Harris and Chan [7]. Our estimate is comparable to participation price elasticity for young adults ($-0.35$) estimated by Tauras [66] and ($-0.416$) by Ross and Chaloupka [67].

These elasticity estimates, summarized in Table 1, reflect the change in probability of being a current smoker that would accompany a given change in

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>15–17</th>
<th>18–23</th>
<th>24–29</th>
<th>30–39</th>
<th>40–65</th>
<th>65 and over</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status as a “current smoker”</td>
<td>– (–)</td>
<td>$-0.0320$ ($0.010$)</td>
<td>$-0.0265$ ($0.008$)</td>
<td>$-0.0175$ ($0.005$)</td>
<td>$-0.0171$ ($0.004$)</td>
<td>$-0.0124$ ($0.004$)</td>
</tr>
<tr>
<td>Elasticity for “current smoker” status</td>
<td>$-0.4155$</td>
<td>$-0.3565$</td>
<td>$-0.2957$</td>
<td>$-0.1809$</td>
<td>$-0.1979$</td>
<td>$-0.3286$</td>
</tr>
</tbody>
</table>

This table presents weighted ordinary least squares estimates from the BRFSS data, 1993–2000. There are 1,000,013 observations. All regressions estimate controls for gender, age, race, education, income, marital status, health status and region effects although not reported. Standard Errors are in parentheses.
cigarette purchase price. For example, if the price elasticity for smoking participation were $-0.3$ for a given population, raising the purchase price of cigarettes by 50% would result in a 15% (0.3 times 50%) decline in smoking prevalence. The simulation model incorporates these elasticities to predict the impact of increased cigarette taxes on smoking participation in the population. We ran scenarios assuming tax increases that raise cigarette prices from as little as 10% above status quo to as much as 100% (a doubling in price), and for all levels of tax-induced price increase at 10% intervals in between.

2.4.2. Raising the smoking age to 21

Although the true impacts of raising the smoking age are unknown, it is plausible that an increase in the minimum purchase age for cigarettes coupled with more rigorous enforcement may reduce youth access to cigarettes. To estimate the potential effect of increasing the MLPA for cigarettes to 21, we made the assumption that its primary impact on smoking behavior would be to reduce or delay adolescent smoking initiation [19]. Specifically, we assume that age-specific initiation rates would shift by 3 years so that an 18-year old in this scenario would have the same likelihood of becoming a current smoker as a 15-year old in the status quo (as depicted in Fig. 1). A 17-year old in this scenario would have the initiation rate of a 14-year old, and so on. Adults aged 21 or older would maintain their current rate for smoking initiation. We acknowledge that there are no empirical data to support this assumption, largely because no state in the US has ever increased the legal smoking age to 21. We varied this assumption in sensitivity analysis and estimated outcomes assuming 2-year and 1-year shifts in youth initiation rates.

Over time, this reduction in youth initiation would reduce adult smoking prevalence because fewer teens would enter adulthood as current smokers and delaying the age of initiation for those who smoke as adults would increase the subsequent probability of cessation [19].

2.5. Sensitivity analysis

To evaluate the sensitivity of outcomes to changes in important parameter values we carried out a sensitivity analysis. For cigarette excise tax increase scenario we varied price elasticity estimates and for increasing the legal smoking age scenario we varied the youth cohort that will be influence by the legislation.

2.5.1. Tobacco taxes

We varied the price elasticity of tobacco excise taxes for sensitivity analysis between $-50\%$ and $+50\%$. We carried out five simulation by changing elasticity by $-50\%$, $-25\%$, $0\%$, $+25\%$, and $+50\%$, where $-50\%$ change means reducing the elasticity by $50\%$, for example, the price elasticity for 24–29-year-old smokers will reduce from $-0.2957$ to $(-0.2957 \times 0.5) -0.1478$. Similarly, a change of $+50\%$ will result in increase in price elasticity to $(-0.2957 \times 1.5) -0.4435$ for the same age group. A 0% change means price elasticity values reported in Table 1 are used without any change (base case).

2.5.2. Age 21

For base case we assumed that age specific initiation rates for 18-, 19- and 20-year olds will change following the enactment of law raising the legal purchase age to 21. Through sensitivity analysis we explored two more conservative alternatives assuming that legislation will result in: (i) change in initiation rates for 18- and 19-year olds, i.e., initiation rates for 20-year olds will not be affected) and (ii) change in initiation rates for 18-year olds only, i.e., initiation rates for 19- and 20-year olds will not be affected. For a scenario where raising the legal purchase age will not reduce smoking at all, results of status quo run (model run without any policy change) will hold.
Table 2
75-Year health impacts of selected anti-smoking interventions in the US

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Smoking prevalence in 2078</th>
<th>Cumulative life years</th>
<th>Cumulative QALYs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15–17-year olds &gt;18-year olds</td>
<td>Total accrued (millions)</td>
<td>Cumulative gain (millions)</td>
</tr>
<tr>
<td>Status quo</td>
<td>22.1</td>
<td>28853</td>
<td>–</td>
</tr>
<tr>
<td>Tax increase (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>21.0</td>
<td>28905</td>
<td>52</td>
</tr>
<tr>
<td>20</td>
<td>20.1</td>
<td>28943</td>
<td>90</td>
</tr>
<tr>
<td>30</td>
<td>19.2</td>
<td>28971</td>
<td>119</td>
</tr>
<tr>
<td>40</td>
<td>18.3</td>
<td>28994</td>
<td>141</td>
</tr>
<tr>
<td>50</td>
<td>17.3</td>
<td>29012</td>
<td>159</td>
</tr>
<tr>
<td>60</td>
<td>16.4</td>
<td>29026</td>
<td>174</td>
</tr>
<tr>
<td>70</td>
<td>15.5</td>
<td>29038</td>
<td>186</td>
</tr>
<tr>
<td>80</td>
<td>14.6</td>
<td>29049</td>
<td>196</td>
</tr>
<tr>
<td>90</td>
<td>13.7</td>
<td>29057</td>
<td>205</td>
</tr>
<tr>
<td>100</td>
<td>12.8</td>
<td>29065</td>
<td>212</td>
</tr>
<tr>
<td>Age 21</td>
<td>7.5</td>
<td>28919</td>
<td>67</td>
</tr>
</tbody>
</table>

3. Results

Table 2 summarizes smoking prevalence and cumulative health outcomes for the U.S. population at the end of the 75-year simulation. The first row presents the status quo scenario, assuming that there is no change in smoking behavior throughout the simulation period. Without intervention, the model predicts that smoking prevalence for 15–17-year olds will be 22.1% in the year 2078, and adult prevalence (for ages 18 and older) will be 22.3%. A total of 28,853 million life years and 24,905 QALYs would accumulate for the population across the 75 years.

The next 10 rows in the column present results assuming various rates of excise tax increases. The first of these rows lists the outcomes assuming that taxes increase nationwide to produce an average 10% price increase for a pack of cigarettes. In this scenario, the estimate smoking prevalence for 15–17-year olds will be 22.1% in the year 2078, and adult prevalence (for ages 18 and older) will be 22.3%. A total of 28,853 million life years and 24,905 QALYs would accumulate for the population across the 75 years.

The intermediate-term effects of increased taxes versus raising the smoking age on 15–17-year-olds’ smoking prevalence are compared in Fig. 2. The horizontal line marked “Status quo” indicates the estimated smoking prevalence in the year 2010 for this age group assuming no changes in initiation, cessation and relapse rates. As a reference point, a line representing the Healthy People 2010 objective of 16% for all high school students (not just 15–17-year olds) is also presented. The 10 bars in solid black represent 2010 prevalence estimates assuming tax-induced prices increases of 10–100%. For example, if taxes are raised to the point that the average per pack purchase price of cigarettes increases by 10%, the smoking prevalence for this age group in 2010 would be approximately 20.1%, adult prevalence would be 16.6%, and a total of 28,943 million life years (for net gain of 90 million above the status quo) and 25,012 million QALYs (an additional 106 million above status quo) would accumulate.

The final row of the table presents outcomes after 75 years the MLPA is raised to 21, and this policy change, in fact, reduces youth access to tobacco and delays smoking initiation as assumed. In this scenario, smoking prevalence drops from status quo levels to 7.5% for 15–17-year olds and to 13.6% for individuals 18 and older. A total of 28,919 million life years (67 million above status quo) and 25,014 million QALYs (109 million above status quo) would accrue over the 75-year period.
just over 20%. The final hashed bar represents the 2010 smoking prevalence for 15–17-year olds assuming the smoking age is raised to 21, but taxes do not increase—just under 9%. Comparing the results of tax increases and raising the MLPA, even doubling the price of cigarettes (the 100% increase scenario) would fall well short of the reduction in 15–17-year-old smoking prevalence by 2010 predicted for raising the MLPA to 21. Fig. 3 makes a similar comparison for 2010 adult smoking prevalence. Again, reference lines marking the status quo adult prevalence of just over 22% and the Healthy People 2010 objective of 12% are included. The solid bars represent prevalence estimates assuming tax-induced price increases ranging from 10% (resulting in a smoking prevalence of approximately 21%) to 100% (producing over 16% prevalence). Under the model’s assumptions, raising the smoking age would produce only a very small decline in adult prevalence to 21.7% (shown in the hashed bar) by 2010. Adult prevalence does not reach the Healthy People 2010 target in any scenario.

Figs. 4–6 compare the long-term effectiveness of setting the MLPA to 21 and raising taxes to various levels. Base case estimates and results from sensitivity analyses of price elasticity and initiation rate shifts are also included. In each figure, horizontal reference

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**Fig. 2.** Youth (15–17-year olds) smoking prevalence in the US in 2010.

**Fig. 3.** Adult smoking prevalence in the US in 2010.
lines indicate the outcome of raising the smoking age to 21 assuming initiation rate shifts of 3 years (the base case), 2 years and 1 year, but assuming no tax increase. The curves plotted in each figure represent outcomes for levels of taxation causing per pack purchase price to increase from 0% (the status quo condition) to 100%. In addition to the base case plots, the results of sensitivity analyses assuming price elasticities 50% lower, 25% lower, 25% higher and 50% higher are plotted for each figure. Any point at which a plotted curve intersects with a horizontal reference line indicates a taxation scenario that produces an effect equivalent to that of raising the smoking age to 21 assuming the indicated shift in initiation rate.

For example, the base case plot in Fig. 4 indicates that smoking prevalence for 15–17-year olds in the year 2078 would range from 22% assuming the status quo (0% tax increase) to under 13% assuming a doubling of cigarette prices (100% tax-induced price increase). No tax increase scenario would produce a youth prevalence reduction equivalent to that predicted for MLPA of 21 scenario (with no tax increase) in the base case (3-year shift).
shift) or assuming a 2-year shift in initiation rate. If initiation rate only shifts by 1 year, however, raising the MLPA to 21 would produce a decline in prevalence comparable to a approximately 68% price increase.

Fig. 5 shows adult smoking prevalence after 75 years. Comparing base case scenarios for both interventions it can be noted that a tax-induced price increase of approximately 40% will result in comparable reduction in adult smoking prevalence offered by MLPA, i.e., smoking prevalence will be just over 13% at the end of the 75-year period for both interventions. If, however, the resulting shift in initiation rate following MLPA is 2 years or 1 year (contrary to 3 years assumed in base case) the level of tax required to achieve comparable reduction in smoking prevalence will be approximately 25% or 12%, respectively. Similarly, an increase or decrease of 25% in price elasticity will shift the breakeven taxation point to 32% or 52%, respectively.

Fig. 6 shows a cumulative gain in QALYs ranging from zero (in the status quo) to 260 million (with 100% tax-induced price increase), and approximately 110 million cumulative QALYs saved assuming a higher smoking age—equivalent to the result of increasing taxes to raise prices by 20%. The equivalent taxation levels are approximately 13% and 7% if shift in age is assumed to be 2 years or 1 year, respectively. An increase or decrease of 25% in price elasticity will shift the breakeven taxation point to 17% or 28%, respectively.

4. Discussion

Adult cigarette smoking prevalence in US is declining as expected but not as desired [68]. In this work, we compare two policy options for their potential to reduce smoking prevalence and estimate resulting health impacts. If youth smoking initiation is delayed as assumed in the model, raising the smoking age to 21 would have little immediate effect on adult smoking, but would bring about a rapid reduction in youth prevalence by reducing initiation. Over time, as more adolescents enter adulthood as never smokers, lower lifetime initiation rates and higher cessation probabilities will produce an overall decline in adult prevalence equivalent to an aggressive excise tax increase (producing a 40% rise in cigarette price). Across a 75-year period, the higher smoking age would yield an increased accumulation of QALYs comparable to what would be observed following a 20% tax-induced price increase—comparable to the average size of all state tax increases enacted since the beginning of 2002.

Although slower to affect youth initiation rates, moderate to high excise tax increases produce an immediate decline in adult prevalence and rapid accumulation of population health benefits by impacting all age groups simultaneously. Plus, even a relatively modest impact on youth smoking translates into lower adult prevalence and adds to the cumulative long-term benefit of the policy.
Modeling outcomes over a 75-year time span allows us to capture the slowly accumulating benefits of a policy change, but requires that caveats be considered when interpreting the results. For example, all intervention scenarios are compared against a status quo condition in which smoking behaviors do not change, even though smoking prevalence has declined in recent years. Although we could have included a modest decline in baseline smoking rates, we presumed that the same forces that would produce such a decline in the status quo would also be present in the intervention scenarios. Rather than introducing one more assumption into the model about rate of decline in smoking prevalence for 75 years into the future without improving the results, we opted to keep the status quo prevalence rate constant. Because the same assumptions are used in all scenarios, the results presented can, at a minimum, be compared to each other.

The impacts of raising the smoking age to 21 require making assumptions in the model. We assume that by increasing the age gap between high school students and legal buyers, coupled with increased enforcement, teen access to cigarettes by commercial and social means will drop, and initiation rates will shift accordingly. We varied this assuming during sensitivity analysis and also considered more conservative changes in initiation rates. Estimates of the potential impacts of the policy change, however, could change using a different assumption, and certainly there is no direct evidence that youth initiation would be impacted at all.

With respect to the tax increase, numerous estimates of price elasticity for smoking participation exist in the literature. For example, price elasticity for adolescents’ overall demand for cigarettes has been estimated anywhere from −0.8 to −1.4 [10]. The overall demand elasticity figure from which we computed adolescent participation elasticity was 0.831 [7], which is on the low end of this range. If the actual elasticity is, in fact, greater than this, smoking prevalence would be lower, and health benefits would be greater than the values reported in this paper. Inflation is not included in the model because we assume that even though cigarette prices will increase in absolute terms over time, they will not change relative to the price of other goods.

Both of the proposed interventions carry with them practical considerations. Raising the MLPA to 21 must be accompanied by strict vendor compliance checks, educating law enforcement, retailer and the public about the policy and more thorough id checking by cashiers—all of which carry costs. Given that each of the hundreds of millions of packs sold nationwide costs society US$ 8.61 in medical care and lost productivity, however, some or all of the policy’s costs will be offset by the savings and benefits it generates [27,28,69].

Additionally, efforts to control youth access to tobacco are typically met with increased “leakage” of cigarettes into the teen population through social means [70]. Even with a higher purchase age and rigorous enforcement, minors will still be able to access cigarettes through social channels, but not easily in a quantity large enough to support a regular smoking habit. Because the policy change would reduce teens’ access to legal buyers in their daily routines and limit their success in buying cigarettes from stores, fewer teens would be likely to obtain enough cigarettes to sustain a high level of consumption. Other sources such as internet vendors with weak age verification procedures would also have to be more tightly regulated to ensure maximum benefit of the policy change [71].

Similarly, tax increases may motivate leakage in the form of smuggling. Black market activity can dilute the effects of tax increases by making cheaper cigarettes available to motivated smokers. Vendors on Native American reservations open additional opportunities to purchase cigarettes in person or over the internet at low prices with little or no tax [72]. Because the proposed policy change is nationwide, it does not create any new incentive for interstate smuggling, but may result in increased smuggling from other countries. Although the exact magnitude of this effect is unknown, research suggests that the impact of smuggling is not large, and smuggling may reduce but will not eliminate the benefits of excise tax increases [73,74].

Another concern surrounding cigarette excise taxes is their potential recesivity [13]. In general, as a proportion of disposable income, excise taxes represent a larger burden to poor people than to more affluent individuals. Because price elasticities for smoking are higher for people with lower incomes, however, raising excise taxes may actually reduce the relative tax burden for poorer individuals as their total cigarette consumption (and expenditure) drops by a greater amount than for more wealthy smokers [75]. Even if this is true in the aggregate, however, policy-makers should be sensitive to the burden high excise taxes may place on individu-
als who do not quit—particularly if a lack of resources is an impediment to cessation.

Both types of anti-smoking interventions discussed here have their own advantages and obstacles which policymakers must balance in pursuing a health promotion agenda. Estimates from our simulation model suggest that impacts of raising the smoking age to 21 may be comparable to the effects predicted for the typical moderate level of tax increases passed in recent years throughout the U.S. Although large excise tax increases would have the largest and most immediate effects on smoking prevalence and population health, if the political climate does not support such a policy, alternatives such as strengthening youth access restrictions by raising the MLPA should be considered.

Acknowledgement

The National Institute of Drug Abuse supported this work through a grant (PHS GrantDA13332) to the University of California Irvine Transdisciplinary Tobacco Use Research Center (http://www.tturc.uci.edu/).

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