Increasing excise taxes on cigarettes in California: a dynamic simulation of health and economic impacts

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Abstract

Background. California raised cigarette excise taxes in 1999, and may generate additional health and economic benefits by raising them further.

Methods. A dynamic computer simulation model follows births, deaths, migration, aging, and changes in smoking status for the entire population of California over 75 years to estimate the cumulative health and economic outcomes of these changes under several excise tax rate conditions (up to 100% price increase).

Results. A 20% tax-induced cigarette price increase would reduce smoking prevalence from 17% to 11.6% with large gains in cumulative life years (14 million) and QALY’s (16 million) over 75 years. Total spending on cigarettes by consumers would increase by $270 million in that span (all going to tax revenue), and those who reduce the number of years spent as a smoker would spend $12.5 billion less on cigarettes. Total smoking-related medical costs would drop by $188 billion. These benefits increase greatly with larger tax increases, with which tax revenues continue to rise even as smoking prevalence falls.

Conclusions. Even considering benefits from the 1999 increase, California has not yet maximized the potential of excise taxes to lessen the negative impacts of smoking. Additional tax increases would provide added health benefits and revenue to the state.

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Keywords: Tobacco policy; Price elasticity; Economic impacts; Health impacts; Cigarette excise taxes in California

Introduction

Despite the highly addictive nature of cigarettes, there is widespread evidence that increasing their price will encourage smokers to decrease or eliminate their consumption and will discourage non-smokers from taking up the habit to begin with [1–3]. This is especially true during adolescence, when around 90% of smokers begin smoking [4] and when demand for cigarettes is more sensitive to price than during adulthood [2]. For these reasons, increasing cigarette excise taxes has tremendous potential to improve public health outcomes by reducing smoking prevalence while, unlike many health promotion interventions, producing a net gain in government revenues.

A $0.50 per pack tax increase (raising per-pack prices around 20%) introduced in California in 1999 with Proposition 10 was estimated to save over 8300 quality adjusted life years and to generate around $700 million in government revenues in the first year alone [5]. Because the greatest impact of the tax hike would be felt by adolescents, the people most likely to initiate smoking, these benefits would increase every year until 75 years past the tax increase.

Even though the 1999 tax increase is already yielding benefits for Californians, the state may not have tapped the full potential of excise taxes to influence tobacco-related outcomes. Since 2002, 35 states and the District of Columbia have increased excise taxes (some more than once), leaving California’s rate of 87 cents per pack as only the 19th highest in the country-well below the national high of $2.05 [6]. California has room to raise excise taxes again to increase the health and economic benefits the state has enjoyed since 1999, and policy-makers and the health...
promotion community should have an estimate of the magnitude of these potential advantages.

This paper presents the results of a dynamic simulation model exploring the accumulation of added benefits for Californians over the next 75 years if excise taxes are raised again today. First, we describe this model and the data it employs. Then, follows a description of our calculation of price elasticity, the calibration of the model, and our method for estimating the outcomes of interest. Next, we present the key findings from the model in terms of the cumulative economic and health consequences of various levels of cigarette price increase for California’s population from 2003 to 2078. Finally, we discuss the significance of the findings and some limitations to our model.

Methods

Model overview

To predict the impacts of tobacco control interventions on key economic and health indicators, we developed a dynamic computer simulation model that can be easily modified to evaluate virtually any policy that affects smoking behaviors [7–9]. We developed the model using Vensim [10], an object-orienting modeling environment. The model uses a state-transition approach with a time step of 1 year to estimate births, deaths, aging, net migration, and smoking status distributions for the population over the next 75 years. Ultimately, the simulation calculates the anticipated cumulative long-term economic and public health gains or losses assuming different levels of cigarette price increase through taxes.

The model schematic is given in Fig. 1. The population is divided into three smoking status categories based on their smoking behavior participation—never smokers, who have smoked less than 100 cigarettes in their lifetime, current smokers, who have smoked 100 or more cigarettes in lifetime and have smoked in the past 30 days, and former smokers, who have smoked 100 or more cigarettes in lifetime, but none in the past 30 days. The initial number of Californians by age and gender come from US Census [11]. The initial smoking status breakdown by age and gender is drawn from the Behavioral Risk Factor Surveillance System [12] and the Teenage Attitudes and Practices Survey [13], and current levels of cigarette consumption for California come from California Department of Health Services [14].

The simulation model begins with data on the starting state of the population (population count and smoking status) by age and gender. Individuals may enter the simulated population, leave it, or change smoking status within the model according to various change probabilities (fertility, mortality, and net migration, rates of smoking initiation, cessation and relapse, and price elasticity of smoking participation) by age group, smoking status, and gender. As individuals move through the model, their ages increase and their subsequent change probabilities are adjusted accordingly.

Change probabilities vary over time as a function of age and gender, and sometimes, smoking status. Fertility [15] is the probability of a live birth as a function of a woman’s age. The number of live births for each year is computed by multiplying the number of women in each age cohort by the corresponding age-specific fertility rate. For each live birth in the simulation, a new never-smoker of random gender and age zero enters the population, and proceeds through the subsequent years of the simulation. Mortality hazard is the probability of death at a given time, and was estimated as a function of age, gender [16], and smoking status [17] assuming a Weibull distribution. The number of deaths each year is computed by multiplying the number of people of each combination of age, gender, and smoking status by that group’s respective mortality hazard, and taking the sum across all groups for each year. Net migration (immigration minus emigration) rates reflect changes due to people moving in and out of the population for each gender and age group and is extracted by age and gender from California Department of Finance data [18].

Age- and gender-specific initiation, cessation, and relapse probabilities are derived from multiple sources. In each case, we estimated change probabilities from survey data by comparing smoking status for 2 consecutive years, using regression methods to fit separate hazard functions by age, gender and interaction terms. Initiation probability was estimated in this way from the Tobacco Use Supplement of the Current Population Survey data. Cessation and relapse probabilities were derived in a similar fashion from National Health Interview Survey...

For every year that follows, the number of never smokers within each age by gender group is multiplied by the corresponding age- and gender-specific initiation probability 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 obtain the number of individuals subtracted from the current smoker group and added to the former smoker group. Similarly, 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.

Public health outcomes are measured in quality-adjusted life years (QALYs), a measure recommended by the US Task Force on Cost-Effectiveness in Health and Medicine [19] to quantify both the number and the health-related quality of years of life lived by a person. QALYs are calculated by assigning to each year of life a quality weight from zero to one, with zero indicating complete disability and one indicating optimal quality, and then summing the weighted life years.

Our model employs quality of life (QOL) estimates that vary with age, gender, and smoking status. We derived these estimates from a polynomial regression on data from two major sources. Kaplan’s Quality of Well Being Scale (RM Kaplan, personal communication, 1999) provided QOL estimates for ages 17 and up. Analysis by Erickson et al. [20] of National Health Interview Survey data provides comparable QOL estimates for children and adolescents. Current smokers have lower health-related quality of life than former smokers, who have lower health-related quality of life than never smokers. For example, the QOL values for current, former, and never smokers, respectively. The dependent variable is dichotomous, indicating whether the *i*th individual in the *j*th state is a smoker in year *t*. The independent variables represent socioeconomic and other factors typically associated with cigarette consumption. *Pjt* is the price of cigarettes in state *j* and year *t*. *Xjt* is a vector of individual characteristics including gender, health status, age, race, education, marital status, and income. *Rjt* is a set of region or state dummies. *Tjt* is a set of year dummies, and *eijt* is a random disturbance term.

The elastic estimation used data from the Centers for Disease Control and Prevention’s (CDC) Behavioral Risk Factor Surveillance System (BRFSS)—a representative survey of each of the fifty states and the District of Columbia stratified by age, sex and race. Because the BRFSS oversamples residents of small states and slightly under-samples whites, men, and younger adults, all estimates are determined using appropriate sample weights. Annual data from each state from 1993 to 2000 (except for 1993, when Wyoming did not participate) are pooled into a single data set, which is then merged with state-specific cigarette tax and price data [24]. Around 6% of available observations were omitted due to missing data, resulting in a final sample size of 1,000,013 observations for the selected time period.

Table 1 presents price coefficients with standard errors and price elasticities used in the dynamic simulation model.
for six age groups: 15 to 17, 18 to 23, 24 to 29, 30 to 39, 40 to 64, and 65 and over. Because the BRFSS does not include individuals under the age of 18, price elasticity for the 15 to 17 age group was taken from Harris and Chan [2], which uses a model similar to ours and reports similar price elasticity estimates to ours for other age groups. Estimates for the remaining five groups were calculated from BRFSS data as described above. Note that younger age groups contain fewer years than older age groups because price sensitivities tend to be less stable in younger people. Price elasticities are lowest for 30- to 64-year-olds, higher for 18- to 29-year-olds and people over 65, and highest for 15- to 17-year-olds. The jump in elasticity observed in young (18–29) and elderly (65+) adults results may be due in part to the lower incomes typical of these ages compared to 30- to 64-year-olds. In general, people with lower incomes are typically more sensitive to price changes [25]. The age group-specific elasticities we computed were used in the dynamic simulation model to estimate changes in smoking behavior resulting from increased cigarette taxes.

Model calibration

To ensure the accuracy of the model, we calibrated it against reliable external estimates of (1) smoking prevalence (never, current and former), (2) population size (by age and gender), and (3) life expectancy (by age, gender, and smoking status). We used external estimates from California Department of Health Services [14], California Department of Finance [26], and American Academy of Actuaries [27] to compare model output for smoking prevalence, population count, and life expectancy, respectively. We compared each model output with reliable existing external estimates, and then made adjustments to select model parameters to improve correspondence. We repeated this exercise until all model outputs were within 1% of corresponding external estimates.

To calibrate smoking prevalence, we started the model in 1995, loading it with historical data. We then ran the model forward and observed the predicted prevalence of current smokers, former smoker, and never smokers in every year from 1995 to 2003. We corrected discrepancies in never smoker prevalence by changing the initiation rate and discrepancies in current and former smoker prevalence by changing cessation and relapse rates. As an example, in 2000, our model estimated that 17.1% of the adult population would be current smokers, this estimates compared favorably to estimates from California Department of Health Services [14], which reported prevalence as 17.1%, respectively.

To calibrate population size, we ran the model forward through the year 2075. We compared population counts for years 2025 and 2050 with California Department of Finance projections for those years [26]. To improve the correspondence between model estimates and Census projections, we made slight increases to fertility and decreases to mortality. In the end, model estimates of population size for both genders and all age groups differed from Census projections by less than 1% for the future years 2025, 2050, and 2075 (for all years, $R^2 = 0.99$). For example, population estimated by model in 2050 is 55.53 million compared to census projections of 54.78 million.

Finally, we compared the simulated life expectancy of current, former, and never smokers to external estimates from the American Academy of Actuaries [27] and Hatton Financial [28] revising mortality rates to improve correspondence. Life expectancy estimates vary by age and gender, but as one example, the model estimated that a 45-year-old female never smoker would live 39.37 additional years and a female current smoker of the same age would live 33.94 additional years. These life expectancy estimates compare favorably with insurance industry estimates of 39.33 and 33.89 years, respectively.

Calculating public health and economic impacts

The model assesses the health and economic consequences of various levels of taxation by first running a status quo scenario with no tax increase using an average price per pack of cigarettes of $3.95 [29]. Then, subsequent simulation runs estimate outcomes for tax increases that raise prices by 20, 40, 60, 80 and 100% (where 100% means the tax increase doubles the price from the status quo condition). Impacts of raising taxes are calculated as the difference between outcomes for each intervention run (with a price increase) and outcomes for the status quo run (with no price increase). The model estimates the accumulation of these outcomes for a 75-year period to ensure that the full impact of the excise tax increase is experienced by the entire population. After 75 years, virtually every individual in the population will have experienced the influence of assumed tax scenario for his or her entire lifetime.
Smoking prevalence is the proportion of the adult population in the current smoker category at the end of the 75-year run. Cumulative life years gained for each level of tax increase is difference of the total of life years lived by the population in each intervention condition and the status quo run. Quality-adjusted life years gained (QALYs) is calculated similarly, taking the difference of the sums of the products of each year of life lived and its age, gender, and smoking status-specific QOL weight for each intervention condition and the status quo.

The number of total packs consumed is the sum of the products of the number of current smokers in the population and the average cigarette consumption for a current smoker in California (53 packs per year [14]) across all 75 years of the simulation. Reduction in packs consumed is the difference between the total packs consumed for each intervention run and the status quo. Money saved by would-be smokers is an estimate of how much less money individuals who spent fewer years as a current smoker in each intervention condition would have been spent compared to their projected cigarette spending in the status quo condition. This is calculated by multiplying the reduction in packs consumed in each intervention condition by the base average per-pack price of $3.95 in the status quo condition. Increased cost to smokers, on the other hand, represents the total increase in spending on cigarettes for those who continue to smoke in each intervention condition and is calculated by multiplying the total number of packs consumed by the increase in price per pack from the base price. Net private spending on cigarettes, the difference in the increased cost to smokers and money saved by would-be smokers, represents the net effect of an excise tax increase on total spending on cigarettes for all consumers in California over the 75-year period.

Additional tax revenue is the difference between total taxes collected in each intervention condition (the increased per pack tax rate times the number of packs sold at the higher price) and the status quo (the base case tax rate of $0.87 per pack [6], times the projected number of packs sold without a price increase). Cumulative medical cost savings is the difference in total public and private medical expenditures for each intervention condition minus those for the status quo.

Results

75-year estimates of health and economic benefits of tax increases

Over the course of the 75-year simulation for California, raising excise taxes would have considerable impact on smoking prevalence, health outcomes, and economic outcomes at all levels of price increase.

Table 2 presents the effects of each level of tax increase on smoking prevalence, life years and QALYs. Compared to the status quo, a price increase as small as 20% would drop adult smoking prevalence from 17.1% to 11.6%, reducing the number of cumulative deaths at the 75-year mark by 557,800 for a total of 14 million life years and almost 16 million QALYs saved across those 75 years.Doubling the price (a 100% price increase) would drop adult smoking prevalence to 5.3% by 2075 and would boost the health benefit to a cumulative gain of 32.8 million life years and almost 37.5 million QALYs over the same time span.

The economic effects of excise tax increases, presented in Table 3, would free up a large amount of money for those motivated to avoid smoking, while increasing tax revenues from increased tax contributions from those who continue to purchase cigarettes at the higher price.

The reduction of smoking prevalence and the concomitant improvement of health outcomes would free up for other uses money that would have been spent on tobacco products and medical care. With a 20% tax-induced price increase, cigarette consumption would drop by close to 3.2 billion packs over the 75 years, saving those who reduce or eliminate time spent as a current smoker nearly $12.5 billion over the 75 years. A 100% price increase from the status quo would reduce consumption by about 7.9 billion packs for savings of over $31 billion. Between $188 billion and $412 billion would be saved on medical costs over that time given a 20% to 100% price increase.

Even with the savings created by reduced smoking participation, however, Californians, on the whole, will spend anywhere between $270 million (in the 20% tax-induced price increase scenario) and $13.9 billion (in the 100% tax-induced price increase scenario) more on cigarette purchases over the 75-years compared to the status quo if taxes are increased. All of the additional costs incurred by smokers, however, will go toward increased tax revenues, which can offset some of the social costs of smoking. These increases in tax revenues would persist at all levels of tax increase even as smoking prevalence declines. Increasing taxes to raise prices by 20% would generate a total of $10 billion in additional tax revenues. If taxes increased until cigarette prices doubled, tax revenues would increase by over $38 billion compared to the status quo, even though smoking prevalence would have dropped by almost two thirds. If prices were increased by as much as 100%, the total tax per pack would have to increase from the current level of $0.87 per pack to $4.82-still well below the CDC’s
estimate of $11.38 per pack of smoking-related medical care costs and productivity loss borne by the state [6].

**Discussion**

The dynamic simulation model shows the great promise of excise tax increases to reduce cigarette consumption and improve health outcomes while generating tax revenues, reducing medical expenditures, and freeing up billions of dollars to be employed in non-tobacco related sectors of the economy. The economic benefits to the state continue to grow with price increases of at least up to 100%, even though cigarette consumption drops by over two-thirds.

A simulation model is only as good as the parameters upon which it operates. Our estimates of input variables were based on the best available data, and where there was uncertainty, we tried to err toward figures that would produce in the model more conservative estimates of the health and economic benefits. For example, price elasticity for adolescents’ demand for cigarettes has been estimated anywhere from 0.8 to 1.4 [5]. The figure we computed, 0.831, is on the low end of this range. If the actual elasticity is, in fact, greater than this, tax revenues would be smaller, smoking prevalence would be lower, and health benefits, health care savings, and money not spent on tobacco would be greater than the values reported in this paper.

We only consider smoking participation rates—not the quantity of cigarettes smoked—in our model. Although the quantity of consumption is related to health and economic outcomes, we did not have the data to model accurately the impact of price change on the amount smoked. It is reasonable to assume, however, that increasing the price of cigarettes would not increase the amount of cigarettes consumed by those continue to smoke. At worst, the results presented underestimate the benefits of a tax increase.

Because adolescents have the highest risk for smoking initiation of any age group and exhibit the highest price elasticity for smoking participation, increasing taxes is particularly effective at improving long-term population health outcomes by reducing the number of new smokers who enter the system. Given that adults rarely initiate smoking, curbing teen initiation will drastically reduce the population’s exposure to cigarettes [5], the incremental health benefit that accrues to the population annually increases with each passing year in every taxation scenario. To give one example, in the 20% tax-induced price increase scenario, the population accrues an additional 24,200 QALYs compared to the status quo in the 10th year of the simulation. By the 75th year of the simulation, the incremental annual health benefit would have grown to 543,500 QALYs.

The level of net private spending on cigarettes increases with a rapidly accelerating slope as a function of the level of tax-induced price increase modeled (producing a large increase in spending from $270 million in the 20% scenario compared to $13.9 billion in the 100% scenario). This is due in large part to the fact that the number of packs consumed decreases with a rapidly decelerating slope as a function of price increase. The increase in private spending on cigarettes price due to higher per-pack prices is offset by a much larger drop in consumption from the 20% to 40% tax increase scenarios than it is from the 80% to 100% scenarios. Therefore, small increases in the per-pack price of cigarettes are offset by large decreases in the number of packs bought, but large increases in price are offset by relatively small decreases in cigarette purchases. This differential accumulates over the 75-year simulation period to produce the substantial increase in private spending on cigarettes reported. As mentioned before, all additional private spending on cigarettes will become additional tax revenue, which can be applied toward offsetting the societal costs of smoking.

We did not find it appropriate to report discounted values for the outcomes of interest. Discounting is employed when a cost incurred in the present is compared to a benefit anticipated in the future, and in this simulation, no positive net costs are incurred at all. 75-year economic outcomes are reported in 2003 dollars for ease of interpreting the true value of the benefits incurred.

Unaddressed in the simulation model is the important issue of smuggling, which may drop price elasticities for cigarettes below our estimates and may introduce additional law enforcement costs. Among the 50 states, there is a strong correlation between cigarette excise tax rates and the prevalence of interstate and international smuggling [30].

Table 3

<table>
<thead>
<tr>
<th>Price increase (%)</th>
<th>Total packs consumed (billion)</th>
<th>Reduction in packs consumed (billion)</th>
<th>Money saved by would-be smokers ($ billion)</th>
<th>Increased costs to smokers ($ billion)</th>
<th>Net private spending on cigarettes ($ billion)</th>
<th>Additional tax revenue ($ billion)</th>
<th>Cumulative health care savings ($ billion)</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>19.28</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
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<td>16.12</td>
<td>3.16</td>
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<td>12.74</td>
<td>0.27</td>
<td>10.0</td>
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<td>5.03</td>
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<td>18.14</td>
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<td>24.79</td>
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Because interstate price differentials create a powerful incentive to transport cigarettes across great distances, some smuggling activity is inevitable [25,31]. Aside from cutting into the tax revenues projected in the model, high rates of smuggling would reduce the effect of the excise tax on cigarette demand (and consequently, on smoking behavior change) by making cheaper cigarettes available to consumers on the black market. Although the exact magnitude of these effects are not known, research suggests that the impact of smuggling is not large, and smuggling may reduce but will not eliminate the economic benefits of excise tax increases [31].

Another important issue is the potential recessivity of cigarette excise tax [32]. In general, as a proportion of disposable income, excise taxes may represent a larger burden to poor people than to more affluent individuals. In the context of smoking, however, because price elasticities are higher for people with lower incomes, some argue that an excise tax increase would actually reduce the tax burden and improve health outcomes to a similar or greater degree for poor individuals compared to rich people as their total cigarette consumption drops by a greater amount [25,33]. Even if this is true in the aggregate, however, policy-makers should be sensitive to the possibility that high excise taxes may put an unreasonable burden on individuals who do not quit—particularly if a lack of resources is an impediment to cessation.

Although these caveats should be considered when discussing further tax increases, it is clear that the overall benefits of raising cigarette taxes are considerable. California has not exhausted the potential of excise tax increases to add to the health and economic benefits it already enjoys. Raising cigarette taxes to levels equal to or greater than those of highest-taxing states should be considered a viable policy option to reduce further the social burden of widespread smoking.

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