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Raising Taxes to Reduce Smoking Prevalence in the US: A Simulation of the Anticipated Health and Economic Impacts

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Abstract

Objective—To estimate health and economic outcomes of raising the excise taxes on cigarettes.

Methods—We use a dynamic computer simulation model to estimate health and economic impacts of raising taxes on cigarettes (up to 100% price increase) for the entire population of USA over 20 years. We also perform sensitivity analysis on price elasticity.

Results—A 40% tax-induced cigarette price increase would reduce smoking prevalence from 21% in 2004 to 15.2% in 2025 with large gains in cumulative life years (7 million) and quality adjusted life years (13 million) over 20 years. Total tax revenue will increase by \$365 billion in that span, and total smoking-related medical costs would drop by \$317 billion, resulting in total savings of \$682 billion. These benefits increase greatly with larger tax increases, and tax revenues continue to rise even as smoking prevalence falls.

Conclusions—Increasing taxes on cigarettes is a unique policy intervention that reduces smoking prevalence, generates additional tax revenue, and results in significant savings in medical care costs.

Keywords

Smoking; Tax; simulation; QALYs; system dynamics; health impacts; economic impacts; price elasticity

INTRODUCTION

Cigarette smoking is now widely acknowledged as the single leading preventable cause of death in the United States¹. Smoking causes more fatalities each year in this country than AIDS, alcohol, cocaine, heroin, homicide, suicide, motor vehicle crashes, and fires combined². On average, smokers die more than six years before non-smokers from causes such as cardiovascular disease, cancer, and emphysema³.

Adverse health effects of tobacco use are estimated to have caused approximately \$157 billion in average annual health-related economic losses between the years 1995 and 1999. Of these losses, \$82 billion are due to annual smoking-attributable productivity costs and \$75 billion are due to smoking-attributable medical expenditures in ambulatory care, hospital care, prescription drugs, nursing homes, and other care facilities⁴.

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Increasing taxes on cigarettes is a widely discussed policy option for reducing smoking prevalence⁵⁻⁷. This paper examines the health and economic consequences of a reduction in smoking prevalence by increasing federal taxes on cigarettes. Numerous studies have identified that while smoking cigarettes is addictive, prices influence the decision to start and quit smoking. This is especially true for adolescents, who are more sensitive to cigarette prices compared to adults^{8,9}. Estimates of price elasticity for smoking participation using individual level data generally range from -0.20 to -0.70 for various age groups¹⁰.

For decision makers considering the policy option of increasing taxes to reduce smoking prevalence, it is important to know both health and economic impacts over the policy horizon. So far, most studies either focus on the reduction in smoking prevalence and mortality following a tobacco tax increase¹¹ or focus on economic impacts such as tax revenues⁵. In this work we estimate both health impacts (smoking prevalence and Quality Adjusted Life Years - QALYs) and economic impacts (savings in medical care costs and increase in tax revenue) over a time horizon of 20 years (up to 2025).

In our previous work⁷ we estimated health and economic impacts of tax increase on cigarettes in California. In this paper we have expanded our work to national level and we have performed a sensitivity analysis on price elasticity. The paper is organized as follows. We first describe the simulation model that we developed followed by details of the data used in the simulation model and the calculation of price elasticity. We then proceed to present the details on the modeling approach, model calibration, and assumptions made to estimate the health and economic impacts of increasing taxes on cigarettes. Model results for different tax increases are reported and the paper concludes with the discussion of results.

METHOD

To estimate the health and economic impacts of tobacco control policies, we developed a dynamic computer simulation model. This model has been used for analysis of different tobacco control policies at state and national level including: raising legal smoking age to 21^{12,13}; taxes on cigarettes⁷; lower nicotine cigarettes¹⁴; low tar cigarettes¹⁵; and comparison of these policies^{16,17}. It is a flexible model that can be used to estimate the health and economic impacts of multiple interventions or policies that changes tobacco use.

The model is developed for the entire U.S. population. The population is divided into three categories based on smoking status, i.e., never smokers, current smokers, and former smokers. Never smokers are individuals who have smoked less than 100 cigarettes in their lifetime. Current smokers are individuals who have smoked 100 cigarettes in their lifetime and have also smoked in the past 30 days. Individuals who have smoked 100 cigarettes in their lifetime, but have not smoked in the past 30 days are categorized as former smokers. We used same definition for never, current and former smokers that is used in the National Health Interview Surveys (NHIS) conducted by Center for Disease Control (<http://www.cdc.gov/nchs/nhis.htm>). For every year, the model tracks population by each individual's age and gender. Births, deaths, and net migration lead to changes in population over time. Three types of smoking behavior changes are simulated: initiation (the transition from being a never smoker to being a current smoker), cessation (current to former smoker), and relapse (former to current smoker). Individuals may change their smoking behavior and become current smoker from never smoker through initiation. Current smokers may cease to smoke and become former smokers, and former smokers may relapse to become current smoker.

Data used in the simulation model

The data used in the simulation model were collected from publicly available sources. The variables used in the model are: population, fertility, mortality, net migration, smoking status (never, current, and former smokers), smoking behavior changes (initiation, cessation, and relapse), quality of life, price elasticity and medical costs.

The population data consists of the number of people by age and gender. Fertility is the probability of live birth and varies with age and over time. Mortality is a function of age, gender, and smoking status and varies over time. For youth and adults, we computed mortality hazard functions for smoking status and gender variables assuming a Weibull distribution, which has been widely used in tobacco-related analyses to model all-cause and disease-specific mortality. Mortality hazard captures the probability of death at time t conditioned on being alive at time $t-1$. For net migration (immigration minus emigration) data, we used middle series projections (by age and gender) from the US Census bureau. Information on smoking status of population comes from the Behavioral Risk Factor Surveillance System and Teenage Attitudes and Practices Survey. Smoking behavior is defined by the probabilities of initiation, cessation, and relapse. Because no single survey includes all data necessary to estimate all behavior change probabilities for all age groups, we used data from several sources. To estimate the probability of initiation, we used the Tobacco Use Supplement of the Current Population Survey. To estimate the probability of cessation and relapse, we used the National Health Interview Survey for adults, and the Teenage Attitudes and Practices Survey (TAPS) II for youth. Using regression methods, we fit separate hazard functions by age, gender, and interaction terms.

To quantify public health outcomes we used the Quality Adjusted Life Year (QALY) measure. The QALY, recommended by the US Task Force on Cost-Effectiveness in Health and Medicine¹⁸ combines improvements in length of life and health-related quality of life into a single measure. For example, 10 years of life at 75 percent quality would result in 7.5 QALYs. To measure the quality of life implications of health problems in adults due to smoking, we used estimates derived from the Quality of Well Being Scale¹⁹. Kaplan elicited separate estimates from male, female, current, former, and never smokers in various age groups starting at age 17. We supplemented these quality of life data for adults with comparable data for youth from Erickson et al.²⁰. They estimated the Quality of Life (QOL) for children using health status data from the National Health Interview Survey. Using the combined data, we used polynomial regression to estimate health-related quality of life as a function of age, gender, and smoking status.

To measure the medical cost implications of raising taxes on cigarettes, for youth we used the medical cost estimates from Medical Expenditure Panel Survey and for adults we used cost estimates from Hodgson²¹. Hodgson combined data from several sources to estimate medical care costs by age group, gender, and smoking status. He obtained data from the National Health Interview Survey, the National Nursing Home Survey, National Medical Care Utilization and Expenditure Survey and Medicare. As one example, Hodgson estimated that the average cumulative medical costs for male smokers over the age interval 55-65 as \$20,420, while the costs for male never smokers of the same age were \$9,830.

Modeling elasticity

We estimated the price elasticity of smoking participation by age group using weighted ordinary least squares method as used by others^{22,23}. We used a standard model of consumption and the estimation function employed is of the following form:

$$Y_{ijt}^k = \alpha + \beta_1 P_{jt}^C + \beta_2 X_{it} + \beta_3 R_j + \beta_3 T_t + e_{ijt}$$

The dependent variable is a dichotomous variable indicating whether the i^{th} individual is a smoker in the j^{th} state in year t . The independent variables are the price of cigarettes in state j and year t (P_{jt}^c), where c stands for cigarettes, a vector of individual characteristics (X_{it}), including gender, health status, age, race, education, marital status, and income, a set of region or state dummies (R_j), a set of year dummies (T_t), and a random disturbance term (e_{ijt}), α is the intercept and β_k ($k=1, \dots, 4$) represent the respective coefficients or vector of coefficients. These variables represent socioeconomic and other factors that are generally associated with the consumption of cigarettes.

The dataset used for this estimation consists of individual level data from the Centers for Disease Control and Prevention's (CDC) *Behavioral Risk Factor Surveillance System* (BRFSS). The survey is designed to be representative by state and is stratified by age, sex, and race. The survey aims to give an accurate picture of the respective demographic groups. For this reason demographic groups that represent a relatively smaller percentage of the actual population get over-sampled. This accounts for possible outliers that might arise if the sampling would be done according to the real percentage-wise representations of the respective demographic groups. In the BRFSS this means small States are over-represented relative to larger States and whites, men, and younger adults are slightly under-sampled. The sample-weights account for this disproportionate sampling and are used in all estimations. Eight years of data from 1993 to 2000 is used by pooling the individual years into one dataset. In all years, data is available for all 50 states and the District of Columbia, except for 1993 when Wyoming did not participate in the survey. The resulting dataset is merged with cigarette tax and price data on the state level measuring the average price of a pack of cigarettes²⁴. Approximately 6 percent of all observations are excluded due to missing information, yielding 1,000,013 observations for the selected time period.

We split the population into five age groups; 18 to 23, 24 to 29, 30 to 39, 40 to 65, and 65 and over. We chose to have fewer years in our youngest two age groups since past research suggests that individual's price sensitivity changes more rapidly during this time. The price elasticity for the age group of 15 to 17 year olds is taken from Harris and Chan²³. This was required as the BRFSS only covers individuals of age 18 and older.

Table 1 shows the price coefficients with standard errors and the price elasticities that we estimated. The results show that younger age groups are more sensitive to prices than individuals between the age of 30 and 65. The elasticities are then used in our simulation model to estimate the smoking prevalence change resulting from price increases.

Model Description

The dynamic simulation model is developed using an object-oriented modeling environment (Vensim)²⁵, which is based on a system dynamics (SD) modeling approach²⁶.

We start the model with an initial population (by age and gender) in 2004 and run the model for 21 years (i.e. until 2025), in one-year increments. The model calculates the population for subsequent years using information on fertility, mortality, and net migration. In a given year, fertility rates for every age are multiplied by the number of women in that age group and smoking status to calculate the number of live births within that year to women of their respective smoking status. Current, never, and former smokers of a given age and gender have different probabilities of dying. The number of individuals in each age, gender, and smoking-status are multiplied by the likelihood of death in that category (as determined from the mortality hazard) to arrive at the number of people dying in that category for a given time increment. Tobacco policies that reduce smoking prevalence save life years because the mortality rates among current smokers are higher compared to mortality rates for never and former smokers for the same age and gender.

The model counts the number of people alive in a given year. By summing over years we get the total life-years lived by the entire US population over the time period of the simulation. By running the model with and without the intervention in place, we get total life-years for both scenarios. The difference between two model runs is the gain or loss in life years. Life years are multiplied with Quality of life numbers to calculate Quality Adjusted Life Years (QALYs). To evaluate the sensitivity of outcomes to changes in important parameter values we carried out a sensitivity analysis of price elasticity estimates.

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 compared each model output with reliable external estimates, and then made adjustments to select model parameters to improve correspondence. We repeated this exercise until all model outputs were within 3 percent of the external estimate.

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 2004. We corrected discrepancies in never smoker prevalence by changing the initiation rate, and discrepancies in current and form smoker prevalence by changing cessation and relapse rates. Our model estimated the current smoker as 21.05 percent of the adult population in 2004. This estimate compared favorably to estimates from CDC, TIPS²⁷ which reported prevalence as 20.9 percent in 2004.

To calibrate population size, we ran the model forward through the year 2025. We compared population counts for years 2000, 2005, and 2025 with US Census middle series projections for that year²⁸. 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 one percent for all years.

Finally, we compared the simulated life-expectancy of current, former and never smokers to external estimates from the American Academy of Actuaries²⁹, 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 impacts

The economic impacts of changes in smoking prevalence, resulting from an increase in taxes on cigarettes, are calculated in terms of savings in medical care costs and changes in tax revenues. We simulate the increase in federal taxes on cigarettes as an increase in cigarette prices from 0 to 100 percent. Where 0 percent federal tax represents the total price at status quo (price plus tax in 2000) and all changes are over and above that price level. Using available price data²⁴ we calculated an average price of 3.37 US dollars per pack of cigarettes in 2000. The simulation model calculates the change in smoking rates due to price increases using price elasticities for each age group. The resulting change in prevalence in conjunction with the change in population size influences the amount of taxes gained or lost, and the healthcare savings realized. Finally, we sum up the gains and losses from taxes, and healthcare savings realized over 20 years and report all values in 2000 U.S. dollars.

RESULTS

Table 2 shows the health and economic impacts of cigarette price changes. We simulated an increase in prices due to federal taxes from 0 percent to 100 percent, with 0 percent change representing the status quo (current tax levels). For example, if federal taxes increase the average price of cigarettes by 40 percent, overall prevalence will drop to 15.2 percent after 20 years compared to a prevalence level of 21.1 percent in 2004. Additionally, it would result in a cumulative gain of 6.95 million life years and 12.92 million QALYs. Further increase in price will result in an additional decrease in smoking prevalence and increased gain in both life years and QALYs. At a 100 percent price increase overall smoking prevalence drops to 11.3 percent and approximately 25 million QALYs will be gained by 2025. Out of the cumulative gain of 25 million in QALYs, 14 million is attributable to mortality and the remaining 11 million to morbidity.

Similarly, if taxes increase cigarette prices by 40 percent, we estimate that 42.7 billion fewer packs of cigarettes will be consumed compared to status quo consumption during next 20 years. We estimate that the government will likely gain \$365 billion in tax revenues, and medical care costs savings will reach \$317 billion, resulting in a total saving of \$682 billion over a period of 20 years. At our upper bound of a 100 percent increase in cigarette price, we estimate a cumulative reduced cigarette consumption of 81.21 billion packs compared to status quo. A 100 percent price increase through tax will result in a gain of \$782.4 billion in cumulative tax revenues and savings of \$600 billion from reduced medical care costs, resulting in a total cost saving of \$1,382 billion.

We varied the price elasticity of tobacco excise taxes for sensitivity analysis. 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 to 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). Results of sensitivity analysis for a 60 % tax induced price increase are summarized in Table 3. For example, changing price elasticity by -25 %, smoking prevalence will increase by 1.2 percent point (i.e., prevalence will be $13.5+1.2 = 14.7$ % instead of 13.5 %); there will be a reduction of 3.42 million in cumulative QALYs gained (14.16 million QALYs compared to 17.58 million). Similarly, reduction in number of packs consumed will decrease by 11.03 billion (reduction in cumulative packs consumed will be 46.75 billion compared to 57.78 billion) and there will be a reduction of \$103.8 billion in total savings (i.e., total cumulative savings of \$841.2 billion compared to \$945 billion). By change price elasticity by + 25 %, smoking prevalence further drops by 1 percent point, and there is gain of additional 3 million QALYs, There will be an additional reduction of 9.66 billion in number of packs consumed and total savings will increase by \$ 90.6 billion.

DISCUSSION

The wisdom of raising taxes on cigarettes has been hotly debated. Advocates of tax increases point out that increasing cigarette taxes may mean better health for those who will quit and savings in terms of medical care costs. Detractors point to loss of revenue earned from taxes due to a decreasing number of smokers. The value of computer simulation is that it offers a way to combine both concerns and the best available data into a single model to estimate the likely cumulative public health and economic consequences over short and long term.

Previous studies^{30,31} have indicated that money employed in other sectors of the economy would result in efficient use of resources and a net increase of overall economic activity. At a

60 percent increase in cigarette price, we estimate that \$945 billion from medical cost savings and tax revenues would be employed in other sectors of the economy over the simulation time horizon (until 2025). This amounts to approximately \$45 billion per year. Our results also show a consistent gain of QALYs at all levels of tax increase. Thus, the tobacco excise tax may offer a unique situation in which the health of the population is increased while at the same time more resources are made available to the government and the economy.

Like all studies that involve estimating future behavior, ours is not free of caveats. We compare tax increase scenarios with a status quo scenario, where no change in tobacco use is expected to occur (holding smoking prevalence at 2004 level i.e., 21 %). We considered the alternative of simulating a modest decline in smoking prevalence under the status quo. However, because the same forces causing a modest decline under the status quo are likely to also be present following any tax increase mandate, smoking prevalence would also decline at higher rates with the intervention. Thus, the incremental value of adding taxes is likely to remain largely unchanged if we had modeled declines under both scenarios, and doing so would have made the model unnecessarily complex.

The actual price elasticity might be higher or lower than what we estimated. While still within accepted limits, our elasticity estimates are on the conservative side of the usual range¹⁰. If the response to price increases is greater than what we assume, tax revenues would be larger, prevalence would be lower, increase in life years and QALYs would be greater, and health care savings would increase as well. Through sensitivity analysis we provide readers an understanding of how different health and economic outcome measures respond to change in elasticity.

We also model price increases to only impact smoking participation rates and not quantities consumed. A change in cigarette prices will also change the amount of cigarettes consumed by smokers. It is however, not easy to predict how the amount of cigarettes smoked, following a price change, will be influenced. While it is possible to estimate current price elasticities for the amount of cigarettes smoked by current smokers, the interaction between those estimates and quitting rates of current smokers following a price change makes these estimates difficult.

When faced with increasing tobacco prices, marginalized groups such as teenagers or homeless individuals adopt smoking habits that pose even greater health risks to them. Such risk behaviors include but are not limited to eliminating the filter, leaving shorter butts, inhaling deep, sharing same cigarette, using hand-rolled cigarettes, or complementing the tobacco in cigarettes with other substances^{32,33}. Our model is not disaggregated by smoker sub-groups, so we do not account for these risky behaviors.

We do not consider gains in labor market productivity and a prolonged working life for individuals who stop smoking^{34,35}. As our estimates of gain in life years or QALYs suggest, the general population will live longer and healthier equating to fewer sick days and more productive work hours. This implies that individuals who stop smoking and individuals who never start smoking because of price increases will realize a net gain in productivity for the economy.

As realized in other studies^{36,37} due to the difficulty in estimating the additional cost of complications arising from smoking (e.g., poor wound healing), these costs are not included. Intangible costs such as the pain and suffering of victims of smoking related diseases and of their friends and relatives should they decease also receive no treatment in our study.

An increase in only the price of cigarettes might raise the use of alternate forms of tobacco. To counter such a development, tax increases should be levied upon all tobacco products, e.g. cigars, loose tobacco, etc.

Smuggling, both interstate and international, currently accounts for approximately 8 percent of cigarette consumption in the US³⁸. International smuggling of cigarettes into the US will certainly increase following any price increases. In response to concerns about smuggling, law enforcement efforts can be intensified, stricter penalties imposed, and cigarette packaging regulated so that legal and illegal cigarettes can be distinguished by law enforcement authorities. We recognize that even with these efforts, some level of “leakage” will always occur. It will be impossible to completely curtail the black market.

Potential recessivity of cigarette excise tax is an issue that has been discussed in the literature³⁹. Excise taxes may represent a larger burden to poor people than to more affluent individuals. Because price elasticities are higher for lower income people, 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 amount⁴⁰. 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.

To summarize, our results suggest that a cigarette price increase through taxes would reduce smoking prevalence, increase the population health, result in a net gain in tax revenue for the government, and will reduce medical care costs. This work should prove helpful to policy makers as they contemplate increasing taxes on tobacco.

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Table 1

Price Effects on Smoking

Dependent Variable	15 to 17 [/]	18 to 23	24 to 29	30 to 39	40 to 65	65 and over
<i>Smoker</i>		-0.0320 (0.010)	-0.0265 (0.008)	-0.0175 (0.005)	-0.0171 (0.004)	-0.0124 (0.004)
Elasticity for <i>Smoker</i>	-0.831	-0.3565	-0.2957	-0.1809	-0.1979	-0.3286

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 Error's are in parenthesis.

[/] Estimates from Harris and Chan (1999) for the age group of 15 to 17 year olds.

Table 2

Public health and economic impacts of cigarettes price increase

Increase in price (%)	Adult Smoking Prevalence (%)	Cumulative gain in LYs (million)	Cumulative gain in QALYs (million)	Cumulative reduction in number of packs consumed (billion)	Cumulative gain in tax revenue (billion)	Cumulative reduction in medical care costs (billion)	Cumulative Total Savings (billion)
0	21.1	--	--	--	--	--	--
20	17.5	3.79	7.22	24.08	194.98	178.7	373.68
40	15.2	6.95	12.92	42.70	364.87	316.7	681.57
60	13.5	9.67	17.58	57.78	516.80	428.2	945.00
80	12.3	12.04	21.52	70.40	655.04	521	1176.04
100	11.3	14.13	24.92	81.21	782.39	600	1382.39

Table 3

Sensitivity analysis of price elasticity at 60 % tax increase

Change in price elasticity (%)	Change in adult smoking prevalence (%)	Change in cumulative gain in Lys (millions)	Change in cumulative gain in QALYs (millions)	Change in reduction in number of packs used (billions)	Change in cumulative gain in tax revenue (billions)	Change in cumulative reduction in medical care costs (billions)	Change in total savings (billions)
-50	2.7	-4.24	-7.36	-23.86	-48.24	-176.50	-224.74
-25	1.2	-2.00	-3.42	-11.03	-22.31	-81.50	-103.81
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	-1.0	1.80	3.02	9.66	19.52	71.10	90.62
50	-1.8	3.45	5.70	18.22	36.84	133.80	170.64