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Original investigation

Has Smoking Cessation Increased? An Examination of the US Adult Smoking Cessation Rate 1990–2014

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Abstract

Introduction: We examine the trajectory of adult smoking prevalence in the United States over the period 1990–2014 to investigate whether the smoking cessation rate has changed during this period.

Methods: We employ a dynamic model of smoking prevalence, and data from the National Health Interview Survey (NHIS) and the National Survey on Drug Use and Health (NSDUH), to estimate the adult cessation rate in 6-year intervals. We use weighted nonlinear least squares to perform the estimation. We then employ a meta-regression model to test whether the cessation rate has increased.

Results: The annual cessation rate has increased from 2.4% in 1990 to 4.5% in 2014 according to the NHIS data, and from 3.2% in 2002 to 4.2% in 2014 according to the NSDUH data. The increasing trend is statistically significant (p value = 1.57×10^{-6}) and the two independent surveys produced nearly identical results, which makes it unlikely that our findings are a product of chance.

Conclusions: Our analysis finds that the smoking cessation rate in the United States has almost doubled since 1990. This increase is responsible for at least 2 million fewer smokers in 2014. If current conditions persist, by the year 2020 the increase in cessation rates will be responsible for 3.5 million fewer smokers. Our findings can assist in predicting the future path of the smoking epidemic and determining the correct allocation of resources to eradicate it.

Implications: We show that the adult smoking cessation rate has greatly increased since 1990. We demonstrate this by studying prevalence trajectories from two independent population surveys, which yielded nearly identical results. Different from other studies, we focus on permanent quit rates (net of relapses) which we estimate from a dynamic model of prevalence. Our results do not stem from self-reported quitting behavior, but from the analysis of observed prevalence and its inherent variability. Our findings can contribute to predicting the future path of the smoking epidemic and to determining the optimal allocation of resources to eradicate it.

Introduction

US adult smoking prevalence has continued to decline over the past decade and a half. For the period 2000–2007, the National Health Interview Survey (NHIS) reported a drop of 3.5 percentage points (from 23.3% to 19.8%), an average rate of 0.50 percentage points per year.[1,2] More recently, for the period 2007–2014, the reported decline was 3 percentage points (from 19.8% to 16.8%), an average rate of 0.43 percentage points per year.[2,3] In terms of proportional or percentage changes, the two periods' declines were virtually identical: dividing the average annual percentage point decrease by the average annual prevalence yields an annual decline of 2.32% for the first period and 2.35% for the more recent period.

Smoking prevalence is the product of the interaction between population dynamics and smoking initiation and cessation. If the rates of smoking initiation and cessation remain the same, prevalence will move toward an equilibrium level at an increasingly slower pace, as projected by previous models of population smoking.[4,5] The fact that US prevalence is declining at a steady pace is an indication that either smoking initiation or cessation, or both, are changing in a desirable direction.

Youth and young adult smoking initiation rates have certainly dropped significantly in the last two decades.[6] Over the period 2000–2014, the NHIS shows a decline from 26.8% to 16.7% in the proportion of adults aged 18–24 who were current smokers.[1,3] Similarly, the Monitoring the Future Survey reports that among 12th grade students, 13.6% smoked in the past 30 days in 2014, compared to 31.4% in 2000.[7]

In contrast with initiation rates, the time trajectory of the adult cessation rate (defined as the proportion of individuals who quit permanently every year) has not been well established. Mendez et al.[4] found that cessation rates increased from the 1970s to the 1980s but did not change significantly between the 1980s and the early 1990s. Additionally, Zhu et al.[8] and Zhuang et al.[9] found no consistent upward trend in quitting over time using data from the 1990s through 2011 from the NHIS and the Tobacco Use Supplement to the Current Population Survey (TUS-CPS). The latter two studies define the annual cessation rate as the percent of smokers who report having quit smoking for at least 3 months in the past year. It is unclear whether this lack of an increase in cessation rates over time would also be evident from examining permanent quit rates (no relapse to smoking) at the population level.

We examine the trajectory of the US adult smoking cessation rate over the period 1990–2014. In contrast with previous research, we use a dynamic model of population smoking prevalence to estimate cessation rates. We evaluate whether the cessation rate has increased over time, or if the steady fall of smoking prevalence is due mainly to the decline in initiation. Correctly assessing these dynamics will play an important role in projecting the future path of smoking prevalence and in planning efforts to further diminish the toll of smoking.

Methods

To estimate the overall adult smoking cessation rate we employ a stock-and-flow approach to describe smoking prevalence as used in a previous dynamic model of population smoking.[4,5] The basic approach can be described by the following ordinary differential equation:

$$\frac{dS(t)}{dt} = \left(I(t) - \left(\mu(t) + \theta(t)\right) \times S(t)\right) \tag{1}$$

where $S(t)$ represents the number of adult smokers in the population at time t, $I(t)$ is the number of new adult smokers per year at time t, and $\theta(t)$ and $\mu(t)$ stand for the cessation and smoker death rates at time t, respectively.

Expression (1) states that the rate of change in the number of smokers depends on the difference between the rate at which new smokers are generated and the speed at which existing smokers leave the smoking pool because of cessation or death. This formulation does not show an explicit link between the rate of new smokers and the size of the pool of smokers, thus treating initiation as an exogenous variable. On the other hand, expression (1) does imply that the smoker exit rate depends on the number of smokers in the population. As such, the cessation rate can be interpreted as the probability that a smoker quits. Because we don't observe actual quitting, but smoking prevalence at different periods, we can only infer the cessation rate net of relapses, which we take as a proxy for permanent quitting. In this work, we consider only permanent quits.

Holding the rate parameters constant over a specified period of time, expression (1) can be solved as:

$$S(t) = \left(S(0) - \left(\frac{I}{\theta + \mu}\right)\right) \times e^{-(\theta+\mu)\times t} + \left(\frac{I}{\theta + \mu}\right) \tag{2}$$

where e is the base of the natural logarithms.

Let $P(t)$ be the size of the adult population at time t. Assuming a constant population P over each time period of analysis, we can express adult smoking prevalence $\pi(t)$ as:

$$\pi(t) = \frac{S(t)}{P} = \left(\frac{S(0)}{P} - \frac{1}{P} \times \left(\frac{I}{\theta + \mu}\right)\right) \times e^{-(\theta+\mu)\times t} + \frac{1}{P} \times \left(\frac{I}{\theta + \mu}\right) \tag{3}$$

Let $\lambda = \frac{I}{P}$ be the smoking initiation rate expressed as the proportion of the adult population that starts smoking every year. Then expression (3) becomes:

$$\pi(t) = \left(\pi(0) - \left(\frac{\lambda}{\theta + \mu}\right)\right) \times e^{-(\theta+\mu)\times t} + \left(\frac{\lambda}{\theta + \mu}\right) \tag{4}$$

We use expression (4) to estimate values for the cessation rate (θ), controlling for the initiation rate (λ). To conduct the estimation, we used adult smoking prevalence data from the NHIS and the National Survey on Drug Use and Health (NSDUH). We use smoking prevalence among 18–24-year-olds as a proportion of the entire adult population as a proxy for the smoking initiation rate, thus assuming that little or no initiation occurs after age 24, consistent with existing data.[10] Notice that, while we restrict prevalence to ages 18–24 to estimate initiation rates (λ), we use adult smoking prevalence for all ages to conduct the estimation of the cessation rate; as such, our cessation rate estimates represent an average across all adult ages.

NHIS and NSDUH are nationally representative household surveys of the civilian non-institutionalized US population and are main sources of data on smoking. Starting in 1990, NHIS smoking data were collected on an annual basis, with the exception of the year 1996. Current smoking is defined in NHIS as having smoked at least 100 cigarettes in one's lifetime, and smoking "now" for 1990 and 1991, or smoking "every day" or "some days" for the years 1992–present. The definition introduced in 1992 was reported to have increased the estimate of smoking prevalence by approximately 1 percentage point[11] so we increased smoking prevalence estimates in

1990 and 1991 by 1 point to adjust for the change in definition. The NSDUH standard definition for current smoking is any cigarette use in the past month, where cigarette use is defined as smoking "part or all of a cigarette." Because of survey design changes in 2002 that prevent comparability with previous years,[12] we excluded NSDUH data prior to 2002 from our analysis. Overall smoker death rates were computed using age-gender-and-year specific smoker death rates obtained from the Cancer Intervention and Surveillance Modeling Network.[13] The Cancer Intervention and Surveillance Modeling Network rates were weighted by the corresponding population size to calculate the overall annual smoker death rate.

Table 1 shows the data used in the estimation procedure by data source, organized in 6-year intervals, except for the last segment that contains 7 years. Column 2 shows the average death rate for each interval. Columns 3 and 4 give each year's adult smoking prevalence (in %) and its respective standard error (*SE*), while "Init Rate" displays, for each interval, the average annual number of new adult smokers over the interval as a proportion of the total population of adults.

Prevalence estimates for NSDUH are consistently 4.5 to 6 points higher than those for NHIS and the initiation rate estimates are twice as large. Ryan and colleagues[14] and, more recently, Haibach and colleagues[15] analyzed the differences and explain the reasons for them in detail. While several factors come into play, the most important distinction lies in which respondents are recorded as nondaily smokers. Estimates of daily smokers are quite similar in the two surveys. NHIS includes as nondaily smokers individuals who have smoked at least 100 cigarettes over their lifetimes and currently smoke "some days." NSDUH asks whether respondents have experienced any cigarette use in the past 30 days (even having smoked "a part of a cigarette"). The latter therefore includes experimenters who have not smoked at least 100 cigarettes lifetime. It also includes recent quitters (within the past month) who would register as former smokers in NHIS. Haibach and colleagues[15] report that the biggest difference between the two surveys is seen for the youngest adult smokers, consistent with our finding that initiation rates (defined as young adult smoking prevalence) are twice as high in NSDUH as in NHIS. While the magnitudes of the prevalence estimates vary considerably, the general patterns of smoking prevalence do not.

We employ weighted nonlinear least squares and the model described by expression (4) to estimate the cessation rate (θ) and initial prevalence ($\pi(0)$) values for each survey in each time interval. To construct efficient estimators for θ and $\pi(0)$, we chose the regression weights as the inverse of the square of the *SE*s reported in Table 1.[16]

We then verified our cessation estimates and their estimated *SE*s using a bootstrapping procedure, sampling prevalence data points from their reported distributions and performing the weighted nonlinear least squares estimation process 10 000 times, each time fitting the model to a random drawing of the data. We obtained nearly identical results from both methods, which lends credence to our estimates.

Finally, to test for an increase in cessation rates over the period 1990–2014, we performed a meta-regression, using the cessation rate estimates for each survey and time-interval as the data to estimate the model.

Table 1. Model Input Data Used to Estimate Smoking Cessation Rates, 1990–2014

		NHIS			NSDUH		
Year	Death rate (μ) (%)	Smoking prevalence (%)	(SE) (%)	Init rate (λ) (%)	Smoking Prevalence (%)	(SE) (%)	Init rate (λ) (%)
1990		26.5	(0.30)				
1991		26.6	(0.20)				
1992		26.5	(0.26)				
1993	0.94	25.0	(0.36)	0.47			
1994		25.5	(0.36)				
1995		24.7	(0.41)				
1996							
1997		24.7	(0.31)				
1998		24.1	(0.31)				
1999	0.88	23.5	(0.31)	0.55			
2000		23.3	(0.26)				
2001		22.8	(0.26)				
2002		22.5	(0.31)		27.5	(0.37)	
2003		21.6	(0.31)		26.9	(0.38)	
2004		20.9	(0.31)		26.6	(0.32)	
2005	0.84	20.9	(0.31)	0.41	26.8	(0.41)	0.83
2006		20.8	(0.36)		26.7	(0.36)	
2007		19.8	(0.41)		25.8	(0.37)	
2008		20.6	(0.41)		25.5	(0.44)	
2009		20.6	(0.36)		25.2	(0.37)	
2010		19.3	(0.31)		24.6	(0.38)	
2011	0.89	19.0	(0.31)	0.35	23.6	(0.40)	0.69
2012		18.1	(0.31)		23.8	(0.37)	
2013		17.8	(0.31)		22.8	(0.33)	
2014		16.8	(0.32)		22.5	(0.29)	

Init Rate = Smoking prevalence among 18–24-year-olds as a proportion of the adult population; NHIS = National Health Interview Survey; NSDUH = National Survey on Drug Use and Health; *SE* = standard error.

To perform the meta-regression, we used a linear mixed model with Gaussian random effects:

$$\hat{\mu}(t) = \beta_0 + \beta_1 \times I_{\text{NSDUH}} + \beta_2 \times t \quad (5)$$

where I_{NSDUH} is an indicator of the data source (1 = NSDUH, 0 = NHIS) and t is a variable that indexes sequential periods. Unstructured between-study covariance was used while the within-study variances were specified using squared *SE*s. The model was fit by maximum likelihood.[17] More information about the estimation procedure is presented in the Supplementary Appendix.

Results

The model presented in expression (4) accords well with the observed data in both surveys. The models' fits to the data are shown in Figure 1 (R^2 = 0.99 for NHIS and 0.98 for NSDUH data).

Table 2 shows, for each period, the mean and the 95% confidence intervals of estimated cessation rates obtained from the weighted nonlinear least squares estimation. Table 3 gives the results of the meta-regression.

Both surveys exhibit an increase in cessation rates over time. The results of the meta-regression indicate a highly significant positive trend in the cessation rate over the period 1990–2014 (p = 1.57×10^{-6}). The results do not find a significant difference in cessation rates between surveys (p = .15).

NHIS data show an 88% increase in the cessation rate from 1990–1995 to 2008–2014 (from 2.4% to 4.5%). The same data also suggest that the cessation rate remained relatively flat between 1997 and 2007 (3.4% to 3.3%). From 1990–1995 to 1997–2001 the cessation rate grew 42% (from 2.4% to 3.4%), and from 2002–2007 to 2008–2014 the cessation rate increased 36% (from 3.3% to 4.5%). NSDUH data suggest a 31% increase in the cessation rate (from 3.2% to 4.2%) between the periods 2002–2007 and 2008–2014. Cessation rates estimated for both surveys over the same period are nearly identical: 3.3% in both NHIS and NSDUH for the period 2002–2007; and 4.5% in NHIS versus 4.2% in NSDUH for the period 2008–2014.

Expression (4) also allows us to calculate the steady state value for smoking prevalence—the eventual value at which prevalence will stabilize—were a given year's rates of initiation and cessation to persist indefinitely. As time increases, the first term of expression (4) decreases to zero, showing the steady state value for the adult smoking prevalence as

$$\text{Steady State Prevalence (SSP)} = \left(\frac{\lambda}{\theta + \mu}\right) \quad (6)$$

Applying the 1990–1995 NHIS values to expression (6), the equation yields

$$\text{SSP} = \left(\frac{\lambda}{\theta + \mu}\right) = \frac{0.47\%}{0.94\% + 2.4\%} = 14.1\%$$

In contrast, applying the values corresponding to the most recent period (2008–2014), we obtain:

$$\text{SSP} = \left(\frac{\lambda}{\theta + \mu}\right) = \frac{0.35\%}{0.89\% + 4.5\%} = 6.5\%$$

This implies a 54% drop in the eventual steady state prevalence (SSP; again assuming that neither initiation nor cessation changes from their current levels). Considering only changes in initiation (ie, assuming no increase in cessation rates since 1990), the SSP would have been 10.5% (a 26% drop). This demonstrates that recent changes in the cessation rate are playing a major role in the current trajectory of smoking prevalence.

Applying expression (4), if initiation and cessation rates had remained at the 1990 levels, smoking prevalence in 2014 would have been 19.8% instead on 16.8%. If the initiation rate had dropped instantly in 1990 to 0.35% (its 2014 value) and the cessation rate had remained at 2.4%, smoking prevalence in 2014 would have been 17.8%. Therefore, the increase in cessation rate between 1990 and 2014 is responsible for at least 1 percentage point decline in prevalence during that period. Similarly, employing the most recent estimates of initiation and cessation rates, expression (4) implies that smoking prevalence will be 14% by 2020. In contrast, if cessation rates had not increased since 1990, the projected smoking prevalence in 2020 would have been 15.7%, a 1.7 percentage point difference due to the increase in cessation.

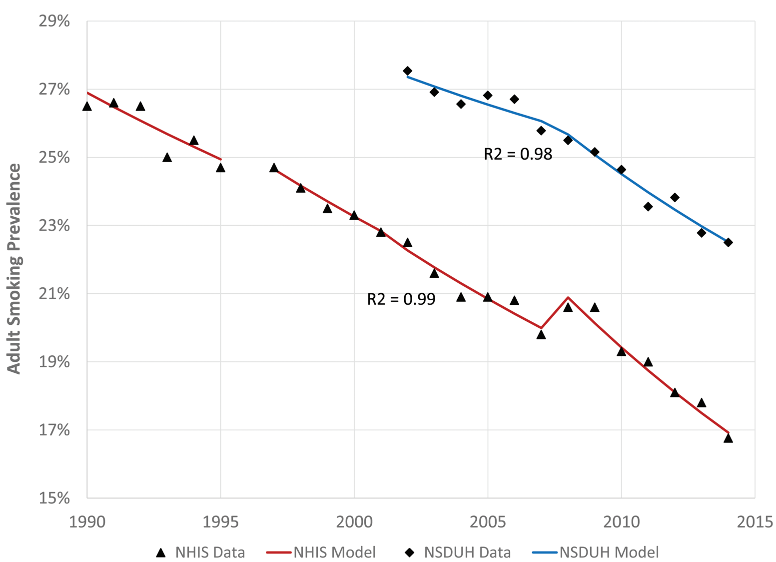

Figure 1. Observed vs. estimated adult smoking prevalence, 1990–2014.

Table 2. Estimated Smoking Cessation Rate and Initial Smoking Prevalence by Period and Survey, 1990–2014

	NHIS	NSDUH		
Period	Initial prevalence (π(0)) (%)	Cessation rate (θ) (%)	Initial prevalence (π(0)) (%)	Cessation rate (θ) (%)
1990–1995	26.9 (26.3, 27.5)	2.4 (1.5, 3.3)		
1997–2001	28.7 (27.8, 29.5)	3.4 (3.1, 3.7)		
2002–2007	30.1 (26.4, 33.7)	3.3 (2.5, 4.0)	31.8 (28.5, 35.1)	3.2 (2.6, 3.8)
2008–2014	44.3 (38.0, 50.6)	4.5 (3.9, 5.1)	43.6 (39.0, 48.3)	4.2 (3.8, 4.6)

Initial Prevalence = Estimated smoking prevalence among adults in 1990; NHIS = National Health Interview Survey; NSDUH = National Survey on Drug Use and Health. Figures in parentheses represent 95% confidence intervals.

Table 3. Meta-regression Results to Test for Changes in Smoking Cessation Rates, 1990–2014

Parameter	Estimate (%)	p
β1 (NSDUH)	−0.4 (−0.9, 0.2)	.16
β2 (t)	0.6 (0.3, 0.9)	$1.26 \times 10{-5}$

NSDUH = National Survey on Drug Use and Health. Figures in parentheses represent 95% confidence intervals.

Discussion

Our analysis finds that the smoking cessation rate in the United States has increased since 1990, and by a lot. In fact, it has nearly doubled, a most impressive development and an encouraging one concerning the future of smoking in this country. A similar earlier analysis did not find any changes in cessation rates from the 1980s through the early 1990s.[4]

Our analysis rested on several assumptions. First, we assumed constant population size and initiation rate over each time segment. To control for the variability across periods in initiation rates in our estimation procedure, we employed the average initiation rate for each individual period (we need to keep the initiation rate constant by time segments to conform to the solution of the differential equation model in expression (1)). These assumptions are unlikely to have affected our results significantly due to the limited variation in population size and initiation rates within a 6-year period.

Second, we did not control for age in our analysis. As such, our quit rate represents an average across all adult ages. As smoking cessation rates vary across age groups, if cessation rates increase with age, it is possible that some of the observed increase in the average cessation rate could be caused by the aging of the population.

The correlation between age and cessation is not straightforward. Mendez et al.,[4] using 1970–1993 data, found that cessation rates increased monotonically with age. However, more recently, some studies have found that older smokers are less likely to quit than are younger smokers.[18] In the latter case, if anything, the aging of the population over the period might bias our analysis to underestimate the increase in the cessation rate occurring in individual age groups. But even if cessation rates were positively correlated with age, the aging of the population would not have played a significant role in the observed surge in the average cessation rate. Using Mendez et al.'s[4] estimates of cessation rates by age group, we calculated that the aging of the population would be responsible for approximately a modest 15% of the total increase in cessation rates during 1990–2013. Future research analyzing trends in cessation rates by cohort and age-group would shed additional light on smoking dynamics over the last decade and a half, and would guide policies to further increase quitting.

Third, we have not considered immigration and emigration in the model. Changes in migration (primarily immigration), and associated differences in smoking rates, theoretically could impact the analysis. However, annual changes in migration account for a very small proportion of the US population. Further, to affect the cessation rate, the rate of immigration would have to change significantly over time and/or the difference in smoking prevalence between current Americans and immigrants would have to change significantly. A previous analysis found that increasing ethnic diversity has contributed modestly to declines in smoking prevalence.[19] Future research could examine trends in quit rates in the context of changing US demographics and migration patterns.

Fourth, our results do not address the fact that the rise in cessation could be associated with individuals switching to other tobacco products, rather than quitting altogether. However, regardless of the extent to which tobacco product substitution may be occurring, cigarettes remain the primary public health concern. As the US Surgeon General observed recently, "The burden of death and disease from tobacco use in the United States is overwhelmingly caused by cigarettes and other combusted tobacco products," with the vast majority of that toll attributable specifically to cigarette smoking.[10]

Finally, we are assuming that there has been no significant change in reporting accuracy on the surveys over the periods covered. It is conceivable that, through changes in who chooses to respond to health surveys or how accurately people respond to questions about a stigmatized behavior, reported smoking could have decreased relative to actual smoking. This, in turn, would produce an upward bias in the more recent years' estimates of cessation rates. However, preliminary results of ongoing research indicate that there has been no major change in reporting accuracy in either NHIS or NSDUH over the relevant years that would produce such a bias.[20]

The NHIS and NSDUH models fit the data very well and yield consistent results. Both models show an increase in the permanent quit rate over time. Moreover, both models show almost identical estimates of the cessation rate for corresponding periods. The meta-regression model results indicate that the cessation rate almost doubled between 1990 and 2014, and that this trend is highly significant.

The evidence suggesting a rise in the cessation rate over time is compelling, not only because of the statistically significant trend between 1990 and 2014, but also because two independent surveys produced nearly identical results, which makes it unlikely that these findings are a product of chance.

The implications of our results are important. The decline in prevalence during the 1990–2014 period has been substantial. In 1990, 25.5% (45.8 million) of the adult population smoked cigarettes compared to

16.8% in 2014 (40.0 million), a drop of 5.8 million smokers despite a 33% increase (58.5 million) in the adult population during this time.[3,21]

According to our model, if initiation and cessation rates had remained at the 1990 levels, smoking prevalence in 2014 would have been 19.8% instead of 16.8%. The increase in cessation during this period is responsible for at least one-third of that three percentage point gap, which translates into 2 million fewer smokers in 2014. Additionally, our model predicts that, by the year 2020, if current conditions persist, the increase in cessation rates (from the 1990 value) will be responsible for a 1.7 percentage point drop in smoking prevalence, or around 3.5 million fewer smokers.

Recently released NHIS data on smoking prevalence for 2015 provide encouraging evidence that cessation may be increasing beyond our estimates. Prevalence reported for the year was 15.1%, an unprecedented decline of 10% from the preceding year.[22]

As to why the cessation rate has risen, we can only speculate. Certainly, elements of effective tobacco control have intensified. Over the past 15 years, half of all US states have adopted smoke-free workplace laws prohibiting smoking in all workplaces including all restaurants and bars. Governmental units have raised cigarette prices through taxation, especially including a federal cigarette excise tax increase of 62 cents in 2009, and by other methods (eg, New York City's establishing a minimum price of $10.50 per pack). Two federal agencies (CDC and FDA) and a foundation (the Truth Initiative) are running national mass media smoking cessation and prevention campaigns. The Affordable Care Act has expanded coverage of smoking cessation treatment. All such evidence-based tobacco control measures could contribute to increased cessation, both directly and indirectly, the latter by virtue of increasing the stigma associated with smoking. As well, it is possible that a significant number of smokers are substituting novel alternative nicotine delivery products, especially electronic cigarettes, for their tobacco cigarettes. We have documented the increase in the cessation rate. We cannot apportion credit for it to these and other factors.

Decreases in smoking initiation have occurred for a long time, but our results suggest that cessation is also improving, and substantially so. This is very good news for public health. While preventing initiation is essential to eventually eradicate the smoking epidemic, the health benefits of quitting are realized much faster than those stemming from prevention.[23] Prevention reduces premature deaths beginning 40 years in the future. Quitting saves lives now.

Supplementary Material

Supplementary Appendix can be found online at http://www.ntr.oxfordjournals.org

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Declaration of Interests

None declared.

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