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Trends in lung cancer and cigarette smoking: California compared to the rest of the United States

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Running Title: Trends in lung cancer and smoking: California vs rest of US

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ABSTRACT

Background: Three cigarette smoking behaviors influence lung cancer rates: how many people start, the amount they smoke, and the age they quit. California has reduced smoking quicker than the rest of the US and trends in these 3 smoking behaviors should inform lung cancer trends.

Methods: We examined trends in smoking behavior (initiation, intensity, and quitting) in California and the rest of US by spline regression analyses using the 1974-2014 National Health Interview Surveys (n=962,174). Lung cancer mortality data for 1970-2013 was obtained from the national Surveillance, Epidemiology, and End Results (SEER) Program.

Results: Among those aged 18- 35 years, California had much larger declines than the rest of the US in smoking initiation and intensity with increased quitting. In 2012-14, among this age group, only 18.6% (95% CI, 16.8%-20.3%) had ever smoked; smokers consumed only 6.3 cigarettes/d (95% CI, 5.6-7.0); and 45.7% (95% CI, 41.1%-50.4%) of ever-smokers had quit by age 35. Each of these metrics was at least 24% better than in the rest of the US. There was no marked California effect on quitting or intensity among seniors. From 1986-2013, annual lung cancer mortality decreased more rapidly in California and by 2013 was 28% lower (62.6 vs 87.5/100,000) than in the rest of the US.

Conclusions: California's tobacco control efforts were associated with a major reduction in cigarette smoking among those under age 35 years. These changes will further widen the lung cancer gap that already exists between California and the rest of the US.

INTRODUCTION

Although lung cancer mortality has declined consistently in the United States (US), it still accounts for over 25% of all cancer deaths,(1) thus, further decreasing lung cancer is a major public health priority.(2) Research reported in the 1950s and 1960s showed that cigarette smoking causes 80-90% of lung cancers(3) and prompted increases in smoking cessation(4) and decreases in smoking initiation,(5) but change was slow.(3) To boost progress, in 1988 California voters passed a dedicated cigarette excise tax and funded the nation's first statewide tobacco control program.(6) Ten years later, a number of states implemented tobacco control programs, funded in part by the Tobacco Master Settlement Agreement.(7) After year 2000, following 12 years of tobacco control leadership, tobacco control expenditures between California and the rest of the country were similar, and California's cigarette prices lagged behind the national average.(8)

As lifetime exposure to cigarettes is important to lung cancer, tobacco control campaigns can target 3 smoking behaviors: initiation, intensity of smoking, and quitting. While preventing initiation is the most effective strategy to reduce the health consequences of smoking in the longer term,(9) promoting cessation among those at near-term risk of lung cancer may achieve more immediate reductions in lung cancer mortality.(10) However, the British Doctor's study determined that individuals who quit smoking at older ages (the peak lung cancer mortality age group) would only gain a small decrease in risk of smoking-related mortality, whereas quitting by age 35 years would avoid almost all later health consequences of smoking, and quitting by age 50 years avoided about half the health consequences.(11) There is also good evidence that reducing the intensity of daily cigarette smoking will reduce lung cancer risk.(12) Since the 1980s smoking intensity has declined in the US, led by reduced peak consumption levels observed for younger cohorts of smokers.(13)

Approaches to reduce smoking behavior have differed considerably across jurisdictions. Most target smokers to quit,(14) emphasizing the health consequences of smoking, sometimes

with hard-hitting advertisements.(15-17) California's program also included competitive grants for community organizers and set their agenda with mass media messages, scientific publications on second-hand smoke exposure[18] (a draft EPA report labelled it a carcinogen in 1990) and industry manipulation of adolescents(19) — together these have been called a "social norm approach" to achieving a smoke-free society.(20) Evidence is needed for the relative success of these different tobacco control approaches to reducing smoking and lung cancer rates.

In this paper, we compare age-specific trends from the 1970s to 2014 (before the rise of e-cigarettes(21)) in smoking initiation, smoking intensity, and cessation in California versus the rest of the US, allowing for a change in the trend after the year 2000. For initiation, we report trends among those under 35 years whose risk of initiation may have been influenced by the California program, as well as the proportion of ever smokers among older populations. As intensity varies considerably depending on smokefree workplaces,(22) we report separately for the younger and older working populations and for seniors. For cessation, we report trends in the proportion who have quit smoking at the 3 target ages (35, 50, and 65 years). Finally, we update trends in lung cancer for California and the rest of the US(23) to examine how California's unique approach to tobacco control might be associated with lung cancer mortality.

METHODS

Data Sources

The National Health Interview Survey (NHIS) has assessed smoking behavior in the United States since the 1960s, obtaining data through a complex, multistage sample design involving stratification, clustering, and oversampling of specific population subgroups that is updated every decade(24). The National Center for Health Statistics (NCHS) uses the design and weighting information to formulate variance estimates for NHIS statistics. We needed geographic variables (California vs rest of US) from each survey for our analyses. We obtained data use agreements and statistical assistance from NCHS Research Data Center to provide

this detail in the late 1990s (for 1974-1995 data) and then in 2016 (for 1997-2014 data). To preserve confidentiality, we collated the 1997-2014 data into 3-year intervals (e.g. 2013 estimate represents 2012-2014 surveys). NHIS annual household sample sizes range from 35,000 to 45,000 and report individual-level response rates of >60% for the period for a total sample of 962,174 respondents. The Census estimates of the California population over this period suggest that it is ~10% of the national sample.

Lung cancer mortality data for California and the rest of the United States were obtained for each year from 1970-2013 from the Surveillance, Epidemiology, and End Results (SEER) Program.(25) Lung cancer deaths are from death certificates filed in the 50 states and the District of Columbia. Age-adjusted lung cancer mortality rates of 35 years or older were calculated using the SEER*Stat software version 8.3.5 (www.seer.cancer.gov/seerstat) and standardized in each calendar year to the 2000 US Census population, using SEER recodes for changes from ICD-8, ICD-9, and ICD-10.(26)

Population-level Smoking Behaviors

In the United States, smoking initiation is assessed with a positive response to the question: “Have you ever smoked at least 100 cigarettes in your entire life?”, thus it ignores limited experimentation with cigarettes. These ever smokers are classified as current or former smokers from their response to: ‘Do you now smoke cigarettes every day, somedays or not at all?’ (prior to 1992, the question was simply: ‘Do you smoke cigarettes now?’). Smoking cessation was defined as the Quit Ratio (former/ever smoker).(27) Smoking intensity was assessed as the number of cigarettes a daily smoker smoked each day, and for non-daily smokers, the average number of cigarettes smoked on days that they smoked (in previous 30 days).

Statistical Analyses

Estimates of ever smoking and smoking intensity were standardized to the 2000 US census by age (18–34, 35–64 and 65+ years), gender, and education (no college vs some college).

Analyses of quitting behavior focus on 10-year age groups with mid-points ages 35, 50, and 65 years (30- to 39-year-olds, 45- to 54-year-olds, and 60- to 69-years-olds). Within each 10-year age group, we standardized estimates to the 2000 Census data by gender and education.

For each of the 3 smoking behaviors, we used multivariable spline regression models comparing California with the rest of the US. We included a knot at the year 2000, as before that year California had higher cigarette prices and more expenditure on tobacco control than the rest of the US, whereas after 2000, California had neither of these tobacco control advantages. (28) We tested for a difference in slope before and after the knot for each location. If there was no significant difference in slope, we removed the knot and report linear regression results (slopes and R^2) of the rate of change over the whole period. All analyses were completed in SAS version 9.3.

We used 2 models for ever-smoking: one focused on respondents under age 35 years (to capture recent initiators) and one for those 35+ years, which would reflect initiation before the California campaign. For smoking intensity, we investigated 3 models: one for younger smokers (18–34 years), a second for the older working-age population (35–64 years), and a third for those in retirement (≥65 years). For quitting, we used 3 models centered on our targeted ages of interest (ages 35, 50, and 65 years). Finally, we plotted age-adjusted lung cancer mortality rates for California versus the rest of the US from 1970 through 2013. We calculated the annual difference in lung cancer rates between the 2 locations and fitted a linear regression line.

RESULTS

Smoking Initiation

In 1974, the prevalence of ever-smokers among 18- to 34-year-olds in California was similar to the rest of the US (47.8%; 95% CI, 46.4%-49.3%) (**Figure 1a**). Through the year 2000, the average annual decline in ever-smoking was twice as fast in California compared to the rest of the US (-0.96%/year, 95% CI,-1.07% to -0.84% vs -0.44%/year, 95% CI, -0.47% to -0.40%,

p<0.0001). After 2000, the rate of decline slowed significantly only in California to a rate similar with the rest of the US. In 2012-14, prevalence of ever-smoking in California was 18.6% (95% CI, 16.8%-20.3%) which was 40% lower than in the rest of the US (31.4%, 95% CI, 30.4%-32.3%, p<0.0001).

Among those 35+ years in the mid-1970s, ~60% of the population in California and the rest of the US were ever smokers. (**Figure 1b**) In the period to 2000, ever smoking declined twice as fast in California compared to the rest of the US (-0.69%/year, 95% CI, -0.53% to -0.85% vs -0.29%/year, 95% CI, -0.39% to -0.19%). After 2000, this rate of decline quickened only in the rest of the US, to a rate similar to that of California. In 2012-14, California had ~20% fewer ever smokers compared to the rest of the US (35.9%, 95% CI, 34.3%-37.5% vs 45.3%, 95% CI, 44.7%-45.8%).

Smoking Intensity

Among 18- to 34-year-old smokers, in 1978, smoking intensity was similar in California to the rest of the US (18.4 cigarettes/d, 95% CI, 17.6-19.1) (**Figure 2a**). A split regression line fit the data well (R^2=0.98). From 1978 to 2000, consumption declined at a 45% faster annual rate in California than in the rest of the US (-0.48 cigarettes/d, 95% CI, -0.40 to -0.56 vs -0.33 cigarettes/d, 95% CI, 0.29 to -0.36). After 2000, the annual rate of decline in smoking intensity slowed significantly only in California to -0.12 cigarettes/d, (95% CI, -0.06 to 0.29). In 2012-14, smoking intensity among 18- to 34-year-old smokers was 30% lower in California (6.3 cigarettes/d, 95% CI, 5.6-7.0) than in the rest of the US (9.2 cigarette/d; 95% CI, 9.0-9.5).

Among 35- to 64-year-old smokers, in 1978, smoking intensity in California was similar to the rest of the US (23.2 cigarettes/d, 95% CI, 22.4-24.0) (**Figure 2b**). A linear regression fit the data well (R^2=0.98). Through 2014, the rates of decline were equivalent to the pre-2000 decline in each respective location for the 18- to 34-year-olds. In 2012-14, smoking intensity in California was 8.7 cigarettes/d (95% CI, 8.1-9.3), which was 37% lower (p<0.0001) than in the rest of the US (12.9 cigarettes/d, 95% CI, 12.7-13.2).

Among smokers aged 65+ years, in 1978, smoking intensity in California was not different to that in the rest of the US (17.8 cigarettes/d, 95% CI,16.2-19.5) (**Figure 2c**). Through 2014, the annual average smoking intensity declined significantly in both California (-0.19 cigarettes/d/yr, 95% CI, -0.11 to -0.26) and in the rest of the US (-0.15 cigarettes/d/yr, 95% CI, 0.-12 to -0.18). In 2012-14, the average cigarette consumption in this age group in California was11.6 cigarettes/d (95% CI, 10.5-12.7), which was 15% lower (p=0.002) than the 13.2 cigarettes/d (95% CI, 12.8-13.6) in the rest of the US.

Quitting by Target Age

In 1978, ~30% of ever-smokers had quit by age 35 years in both California and the rest of the US. **(Figure 3a**). The model for both locations was an adequate fit to the data (R^2=0.61). From 1978 to 2012-14, the quit ratio increased consistently at 0.38%/year (95% CI, 0.16%-0.60%) in California. In the rest of the US, there was no increase until after 2000, when the rate became similar to that in California. In 2012-14, the quit ratio in California was 24% higher than in the rest of the US (45.7%, [95% CI, 41.1%-50.4%] vs 37.8%, [95% CI, 36.1%-39.4%] p=0.0007).

In 1978, the proportion of ever smokers who had quit by target age 50 years was similar in California and the rest of the US (30.7%, 95% CI, 27.1%-34.4%). (**Figure 3b**) From 1978-2014 the model was an adequate fit to the data (R^2 =0.65) and, quitting increased in California at a consistent rate of 0.4%/year (95% CI, 0.15%-0.65%). Prior to the year 2000, quitting increased at the same rate in the rest of the US. However, after 2000, the quit ratio actually declined through 2014 (-0.37%/year, 95% CI, -0.06 to -0.68). In 2012-14 the quit ratio was 27% higher in California than in the rest of the US (56.3%, 95% CI, 51.6%-60.9% vs 46.4%, 95% CI, 44.7%-48.1%).

In 1978, approximately half of ever smokers in California and the rest of the US had quit by age 65 years. (**Figure 3c**). A linear regression line fit the model well (R^2=0.79). The quit ratio increased consistently and slightly faster in California (0.65%/year, 95% CI, 0.31%-1.00%) than in the rest of the US (0.55%/year, 95% CI, 0.44%-0.67%) with no evidence of a change in slope

through 2014. In 2012-14, there was no difference in the proportion of ever smokers who had quit in California compared to the rest of the US (64.9%, 95% CI, 63.3%-66.5%).

Lung Cancer Mortality

In 1970, lung cancer mortality was higher in California (76.3/100,000) than in rest of the US (71.5/100,000) (**Figure 4a**) and climbed consistently in both locations through 1985 (California = 107.8/100,000; rest of the US = 106.2/100,000). It continued to climb in the rest of the US to peak in 1993 at 116.8/100,000, which was 7% higher than California's 1985 peak. After a few stable years, lung cancer mortality in California declined consistently from 1991 through 2013, at an average rate of ~2/100,000/year to 62.6/100,000. In the rest of the US, lung cancer mortality also declined after its 1993 peak through 2013 to 87.5/100,000 (rate of 1.5/100,000/year). As the consistent rate of decline in California was 33% faster than the rest of the US, the gap in lung cancer mortality grew at a rate of 0.93%/year (95% CI, 0.88%-0.97%). In 2012-13, lung cancer mortality was 28% lower in California compared to the rest of the US (**Figure 4b**).

DISCUSSION

In its first 12 years, California's tobacco control program had an important impact on smoking behavior, particularly among the younger ages, compared to the rest of the US. California experienced a rapid decline in smoking initiation in those under 35 years and a major decline in intensity of smoking among those of working age. Although there was no marked state-level effect on cessation among smokers at near-term risk for lung cancer (i.e. seniors), the program was associated with increased cessation before age 35 years. However, after the year 2000, a weakened California program and increased tobacco control in the rest of the country cancelled out the year-over-year California gains. Nevertheless, in 2012-14, among those under 35 years, the combination of a 39% lower initiation rate, a 30% lower intensity among continuing smokers, and a 24% higher cessation rate meant that young Californians had much less exposure to cigarette smoking than those of similar age in the rest of the country.

In the 1970s, California did not have the advantage of lower smoking initiation, lower intensity among smokers, and higher cessation, and, indeed, lung cancer mortality was higher than in the rest of the US. However, smoking behavior changed earlier in California than in the rest of the US, and this was associated with lung cancer mortality peaking earlier and then, over the past 20 years, declining almost 1% consistently faster compared to the rest of the US. Should current trends continue, in 2037, lung cancer mortality will be 50% higher in the rest of the US than in California. No doubt this increased decline in California is attributed to the increasingly lower rate of ever smoking seen among older Californians as well as to the marginally higher cessation rates and lower smoking intensity observed in these same populations. However, the dramatic difference in exposure to cigarette smoking among those under the age of 35 years can be projected to dramatically increase the annual gap in lung cancer mortality when these cohorts mature to the ages most at risk for lung cancer.

California's Tobacco Control Program started just as the Environmental Protection Agency released its first draft of a report labelling secondhand smoke as a class A

carcinogen.(29) The program focused on social norms, providing funding for local community organizers focused on this newly recognized carcinogen.(20,30) There followed a rapid increase in local ordinances restricting where smoking was allowed.(31) The Program highlighted tobacco marketing as a major influence on adolescent smoking,(32) which was followed by a number of ordinances restricting advertising near schools. In 1994 California passed the first state legislation that mandated smokefree workplaces, restaurants and bars, some 8 years ahead of the next jurisdiction.(33) Major changes were documented in protecting non-smokers from secondhand smoke, particularly children and indoor workers.(34) While the Program pioneered Quitlines,(35) it did not promote cessation through a health care system approach as was done in the UK.(36) By the mid-1990s, California had implemented a program to limit underage tobacco purchases and promote smoke-free school campuses.(37) After 17 years of failing to get voters to further increase the tobacco tax, in 2016, voters approved a $2 increase in tobacco excise taxes, revitalizing the California Tobacco Control Program. The question remains whether this will be sufficient to recapture the momentum towards a smoke-free society so evident in the 1990s, particularly with the rise of the e-cigarette usage (38) and the evidence that this may herald an increase in cigarette smoking in young people. Given that the California program differs from other lauded tobacco control programs (e.g. New York, Australia), it will be important to compare the differential impact of these programs on smoking behavior, and insightful to learn if any have had a significant impact on quitting among seniors.

If, as we strongly expect, smoking behavior is the reason for the more rapid decline in lung cancer in California, then we would expect that the decline would be more marked in the smoking-related histological subtypes of cancer (squamous cell and small cell lung cancer) than in adenocarcinoma. (39) Further research examining trends in lung cancer subtypes would strengthen the conclusions that smoking is the cause of the much more rapid decline in lung cancer in California. It is possible that the faster decline in lung cancer mortality in California reflects a greater dissemination of lung cancer early detection programs that result in early

stage diagnosis and more effective treatment (40). However, most lung cancers are diagnosed when patients present with symptoms, indicating advanced stage disease that is difficult to treat. While the National Lung Screening Trial (41) demonstrated a 20% reduction in mortality with low-dose CT (LDCT) screening, concerns such as how to treat large numbers of false positive findings have limited widespread dissemination (42). An analysis of trends in lung cancer stage between California and the rest of the US will be needed to rule out this unlikely hypothesis.

A strength of this study is that smoking behavior measures are from the NHIS, the longest running US survey on tobacco use. A limitation is that the NHIS is not designed to provide representative estimates of state data. However, NHIS estimates of smoking prevalence for California have been shown to be similar to estimates from other surveys that were designed to make state-representative estimates.(43) A strength is that lung cancer mortality was obtained from death certificates collated through population registries.

California's tobacco control program, a pioneer in targeting the social norms around smoking, was associated with a major decline in cigarette smoking among those under 35 years and a reduction in smoking intensity in working aged populations, but did not influence quitting among seniors. For the past 2 decades, lung cancer mortality has decreased faster in California than the rest of the US mainly from earlier reductions in smoking initiation. These California-specific reductions in cigarette smoking in younger populations should result in considerably lower lung cancer mortality in these younger birth cohorts.

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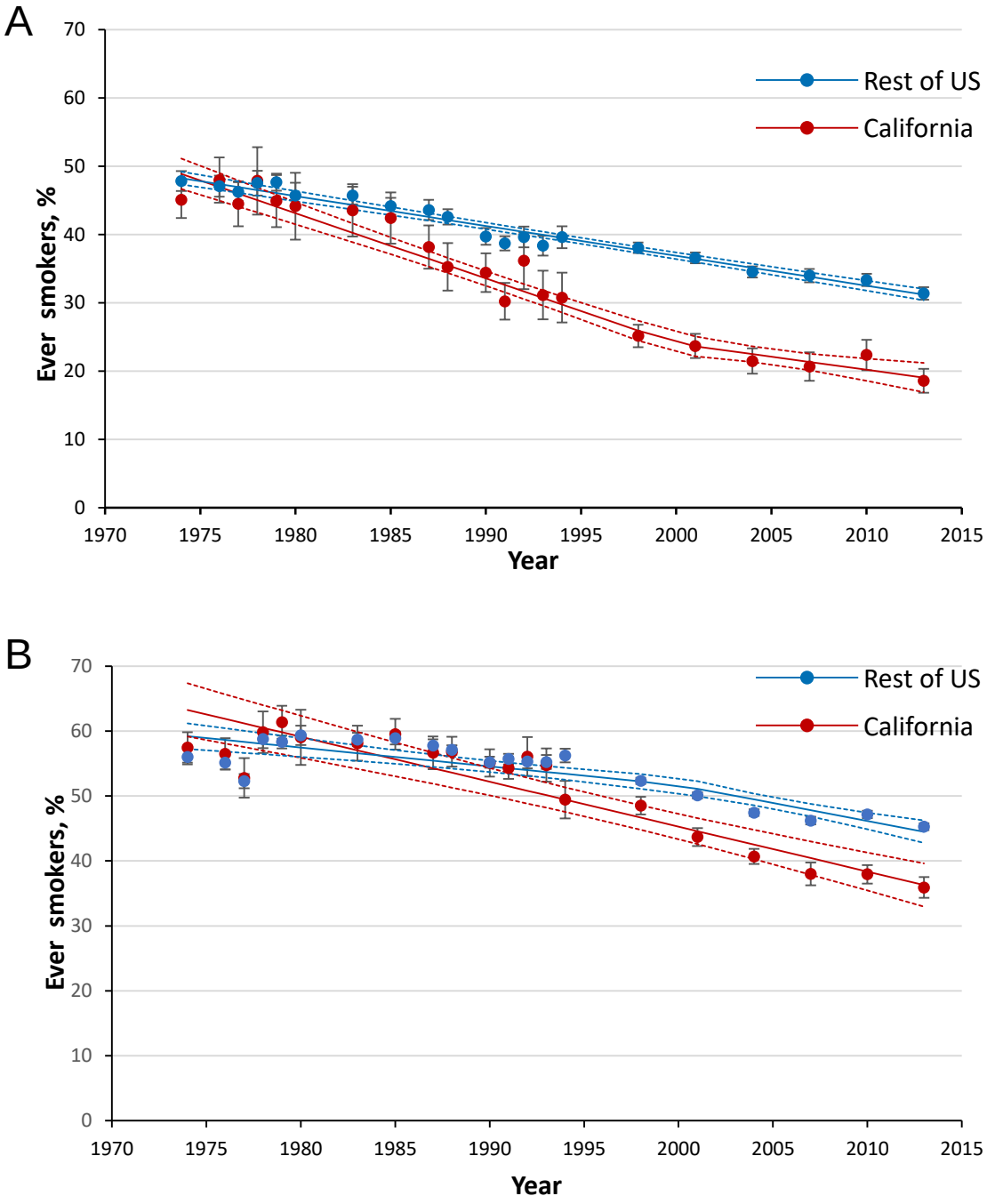

Figure 1. Trends in smoking initiation in California and the rest of the United States, 1974-2014 among **(A)** 18- to 34-year-olds and **(B)** individuals aged ≥35 years. Data Source: National Health Interview Surveys. Data for years 1997-2014 are collated over a 3-year period (e.g., 2013 point estimate represents years 2012–2014). Error bars represent the 95% confidence intervals.

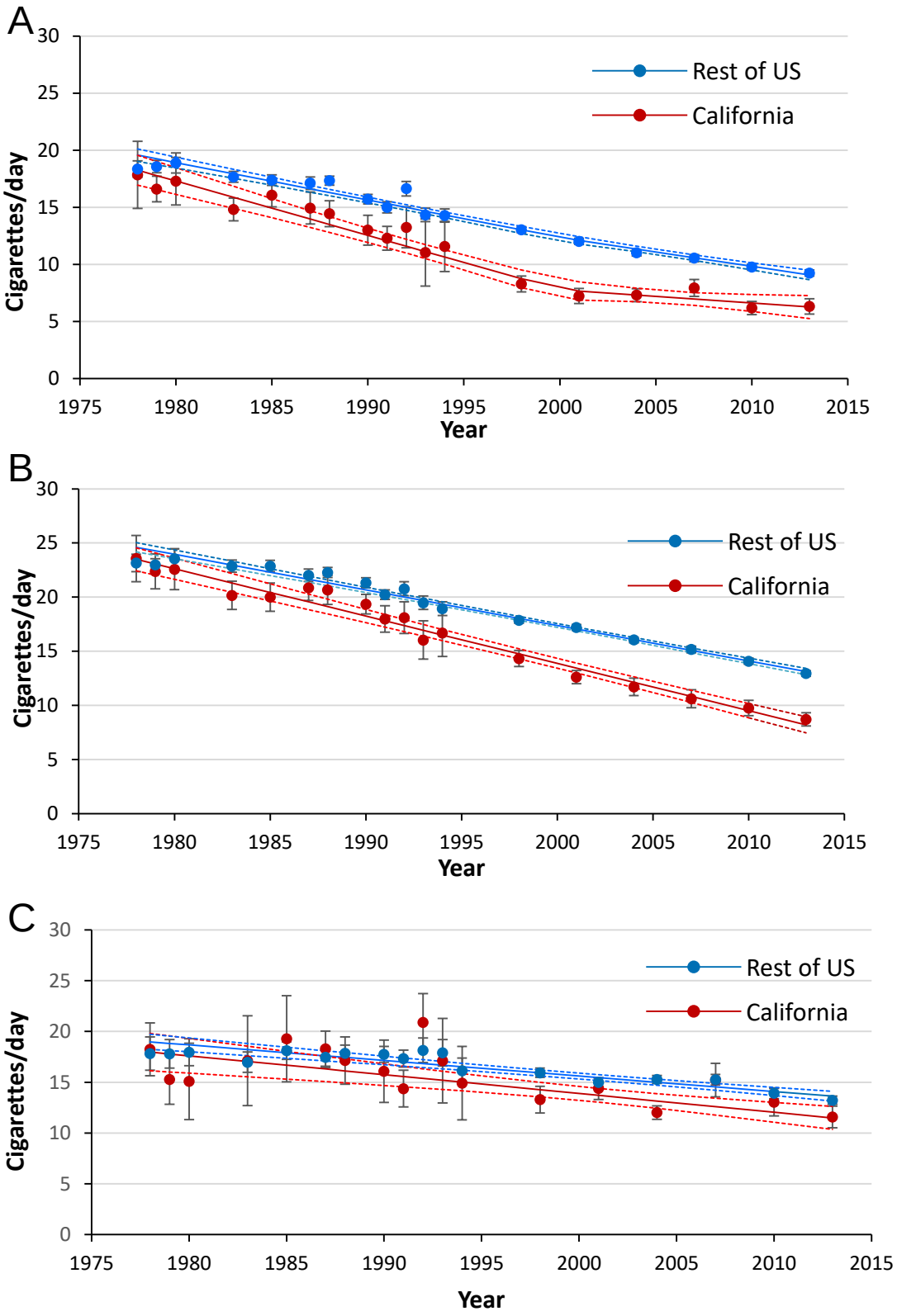

Figure 2. Average daily cigarette consumption in California and the rest of the US, 1978-2014 among **(A)** 18- to 34-year-old smokers **(B)** 35- to 64-year-old smokers and **(C)** smokers aged 65+ years. Data Source: National Health Interview Surveys. Data for years 1997-2014 are collated over a 3-year period (e.g., 2013 point estimate represents years 2012–2014). Error bars represent 95% confidence intervals.

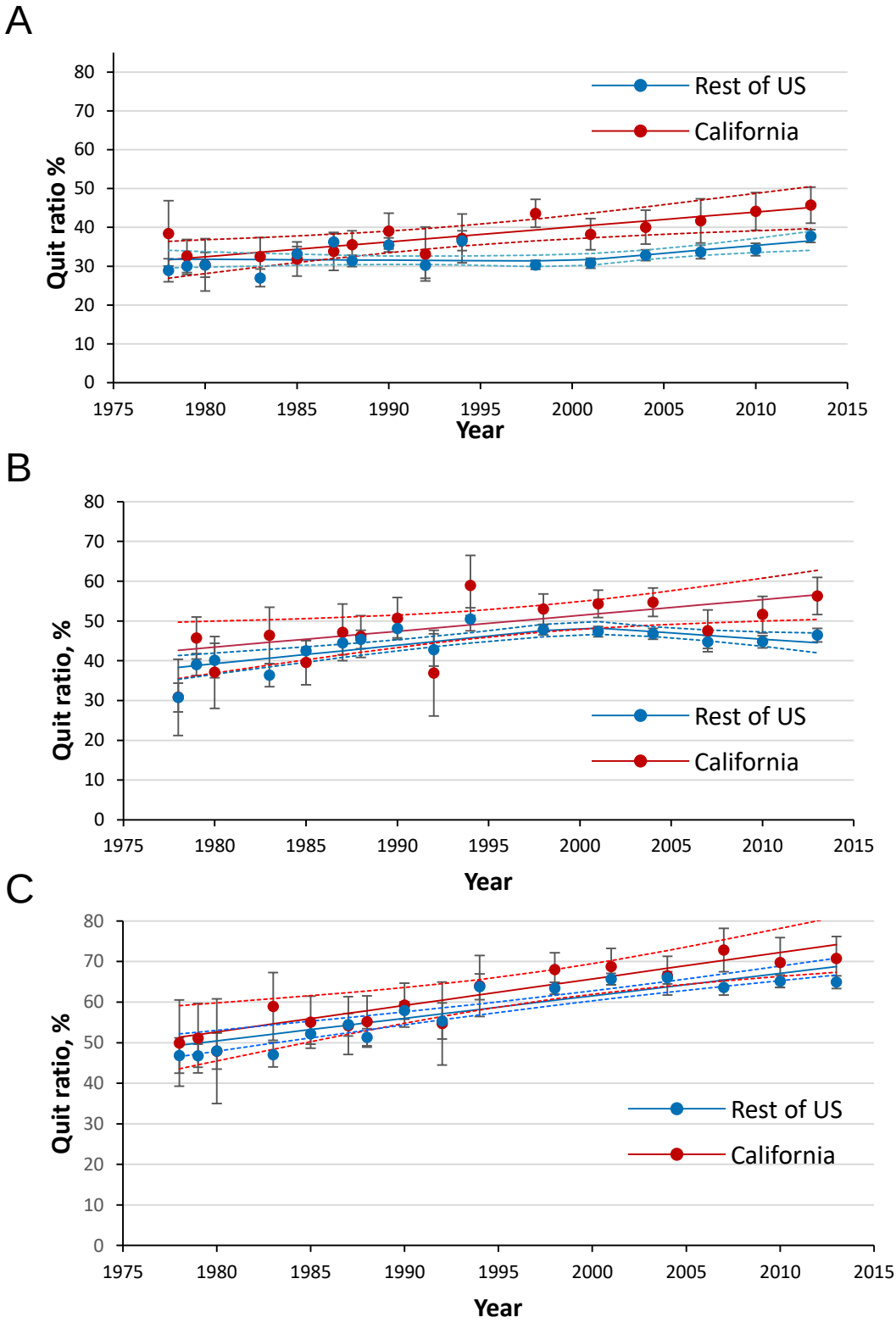

Figure 3. Trends in smoking cessation in California and rest of the United States, 1978-2014 for **(A)** quitting by target age 35 (among 30- to 39-year-old ever smokers) **(B)** quitting by target age 50 (among 45- to 54-year-old ever smokers) and **(C)** quitting by target age 65 (among 60- to 69-year-old ever smokers). Data Source: National Health Interview Surveys. Data for years 1997-2014 are collated over a 3-year period (e.g., 2013 point estimate represents years 2012–2014). Error bars represent 95% confidence intervals. Quit Ratio is the ratio of former smokers to ever smokers.

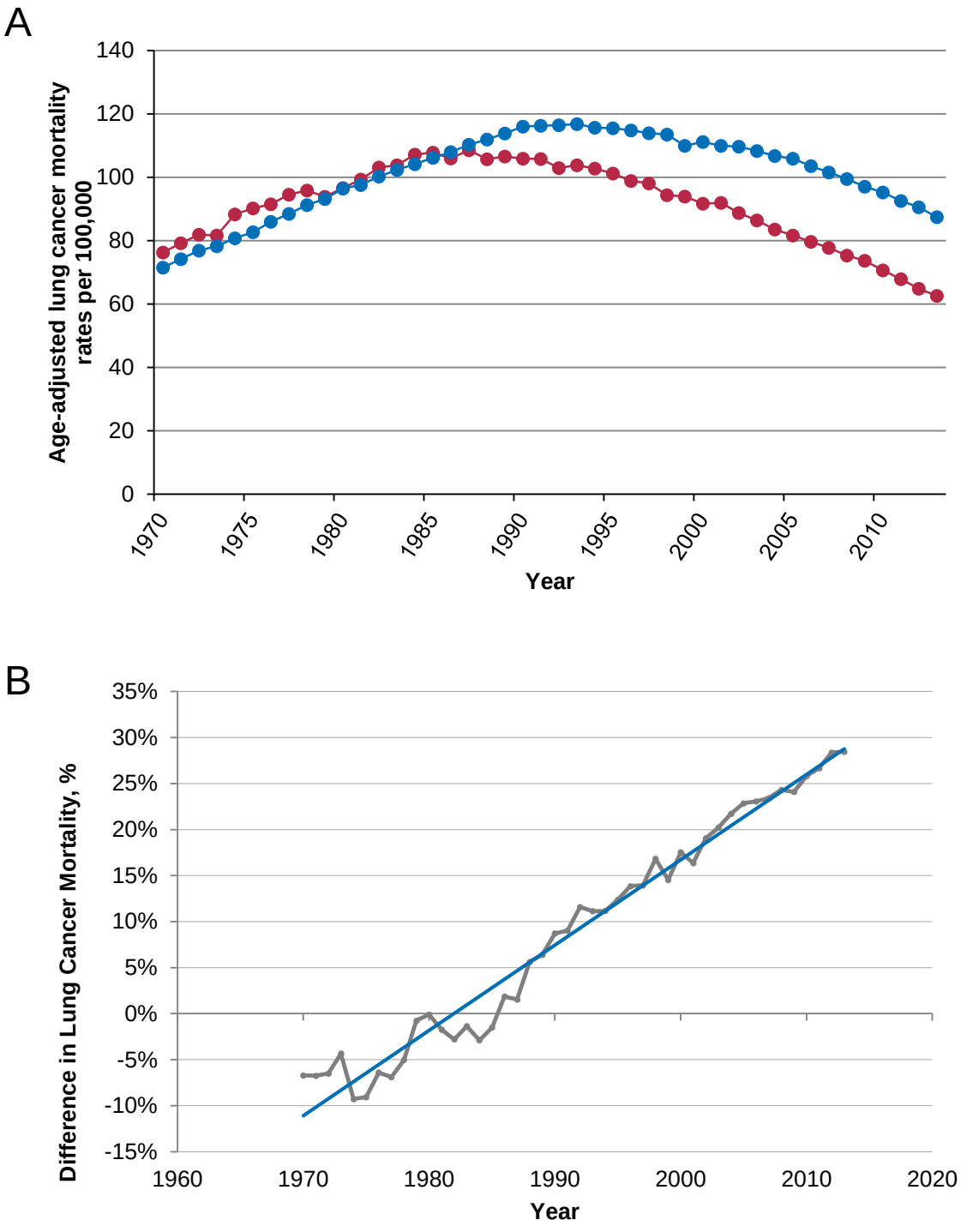

Figure 4. Trends in lung cancer mortality in California and the rest of the United States, 1970-2013 expressed as **(A)** age-adjusted lung cancer mortality rates per 100,000 and **(B)** percent difference in lung cancer mortality (year change slope= 0.93% and R2= 97.26%). Data Source: Surveillance, Epidemiology, and End Results (SEER) Program SEER*Stat Database.