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Smoking prevalence following tobacco tax increases in Australia between 2001 and 2017: an interrupted time-series analysis

Anna L Wilkinson, Michelle M Scollo, Melanie A Wakefield, Matthew J Spittal, Frank J Chaloupka, Sarah J Durkin

Summary

Background Building on substantial tobacco control action over the previous decade, Australia increased the taxes on tobacco by 25% without forewarning on April 30, 2010. Australia then became one of a few countries to pre-announce a series of increases in tobacco taxes, with annual 12·5% increases starting from December, 2013. We aimed to examine the effects of both tax increases on smoking prevalence.

Methods By use of survey data from Australians aged 14 years and older in five capital cities, we did an interrupted time-series analysis to model the monthly prevalence of smoking (overall, of factory-made cigarettes [FMC], and of roll-your-own tobacco [RYO]), in the total sample and stratified by socioeconomic status subgroups. We measured outcomes in May, 2001–April, 2010; May, 2010–November, 2013; and December, 2013–April, 2017.

Findings The 25% tax increase was associated with immediate (–0·745 percentage points; 95% CI –1·378 to –0·112) and sustained reductions in prevalence (monthly trend –0·023 percentage points; –0·044 to –0·003), which were driven by reductions in the prevalence of smoking of FMC. The prevalence of smoking of RYO increased between May, 2010, and November, 2013, after the 25% tax increase. At the start of the pre-announced annual 12·5% increases, we observed an immediate reduction in smoking (–0·997 percentage points; –1·632 to –0·362), followed by decreasing overall prevalence (monthly trend –0·044 percentage points; –0·063 to –0·026) due to ongoing decreases in the prevalence of FMC smoking and a cessation of increases in the prevalence of smoking of RYO. Immediate decreases in smoking and changing trends in the prevalence of smoking of RYO were most evident among groups with a lower socioeconomic status.

Interpretation Large tax increases are effective in reducing smoking prevalence, both as a single increase without forewarning and as a pre-announced series of increases. However, taxes on tobacco are best structured to apply equally to FMC and RYO products. Tobacco control policies should prohibit price marketing that otherwise erodes the full impact of such tax increases.

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Introduction

Reducing tobacco use is a global public health priority, given the wholly preventable associated morbidity and mortality. International agencies[1,2] recognise tax increases as a cost-effective intervention in reducing tobacco use.[3,4] Sufficiently large increases in tobacco taxes reduce overall tobacco use,[3] with price elasticity estimates converging around a 0·4% reduction in tobacco consumption in high-income countries[3] and a 0·5% reduction in tobacco consumption in low-income and middle-income countries for every 1% real increase in price.[5] Tobacco tax increases demonstrably reduce the amount that people smoke, prompt quitting, and reduce the number of people starting smoking.[3,4] Smokers in lower socioeconomic groups have been more responsive to tobacco product price increases.[3] However, tobacco companies are known to engage in pricing and other marketing strategies[6] that can reduce the effects of tax increases.[7,8] Those on lower incomes[9] can be more vulnerable to such industry mitigation, potentially undermining the effectiveness of tobacco tax increases, particularly within these populations.

Australia is a nation with advanced tobacco control, having implemented mass-media campaigns, smoke-free environments, access to cessation aids, regulation of marketing, pictorial health warnings, and world-first standardisation of tobacco product package design (figure 1).[10] Biannual indexation of excise and customs duty on tobacco products since 1984 has helped to prevent tobacco products from becoming more affordable over time.[11] On April 30, 2010, a 25% increase in tobacco tax was implemented in Australia, with no forewarning;[12] this increase was the largest in Australia's history and one of the largest globally. In August, 2013, the Australian Government announced a series of four 12·5% annual tobacco tax increases, with the first increase implemented on Dec 1, 2013, and subsequent increases on Sept 1, for the following 3 years.[13]

Research in context

Evidence before this study

We searched PubMed with the search terms: "smok*" (ie, smoking; smoker or smokers; smoked; smoke or smokes; smoke-free); "cigar*" (cigar or cigars; cigarillo or cigarillos; and cigarette or cigarettes); and "tobacco". We reviewed titles and abstracts, and we excluded articles not in English, that did not use a human sample, or that were not relevant to tobacco use or policy. Given the extensive literature on tobacco control and tobacco taxation specifically, we included seminal reports and studies and any studies that were specific to large tax increases or to Australasia. Previous work consistently showed that tobacco tax increases are an effective intervention to reduce tobacco use in low-income, middle-income, and high-income countries. Regarding the effects of very large tax increases, one study in a single Australian jurisdiction found an increase in quit attempts after the 25% increase in tobacco tax in Australia, but the study only evaluated the effects for 3 months of follow-up. Two studies assessed the effects of 10% annual tax increases that were implemented in New Zealand in January, 2010; however, these studies were before-and-after comparisons among a small sample of smokers, using no more than 6 months of follow-up. Price monitoring in the UK has documented tobacco companies increasing prices gradually ahead of and after tax increases announced each year in the UK Budget, thereby cushioning the effects on consumers. Researchers have called for tax increases to be introduced without forewarning, to circumvent industry mitigation. We found no studies that examined the effects of a series of pre-announced increases in tobacco taxes on smoking prevalence at a national level that used extended population-level outcome data.

Added value of this study

To our knowledge, this is the first study internationally to examine the short-term and long-term effects of two different approaches to implementing large increases in tobacco tax on population smoking prevalence, both overall and in population groups. Our study used a robust analysis approach, with estimates adjusted for other tobacco control policies. Our findings provide evidence that both major tax policy initiatives were effective in the short term and the longer term. Our results also provide insights into the potential for the tobacco industry to mitigate the effect of increases if taxes are not congruent across different forms of tobacco products.

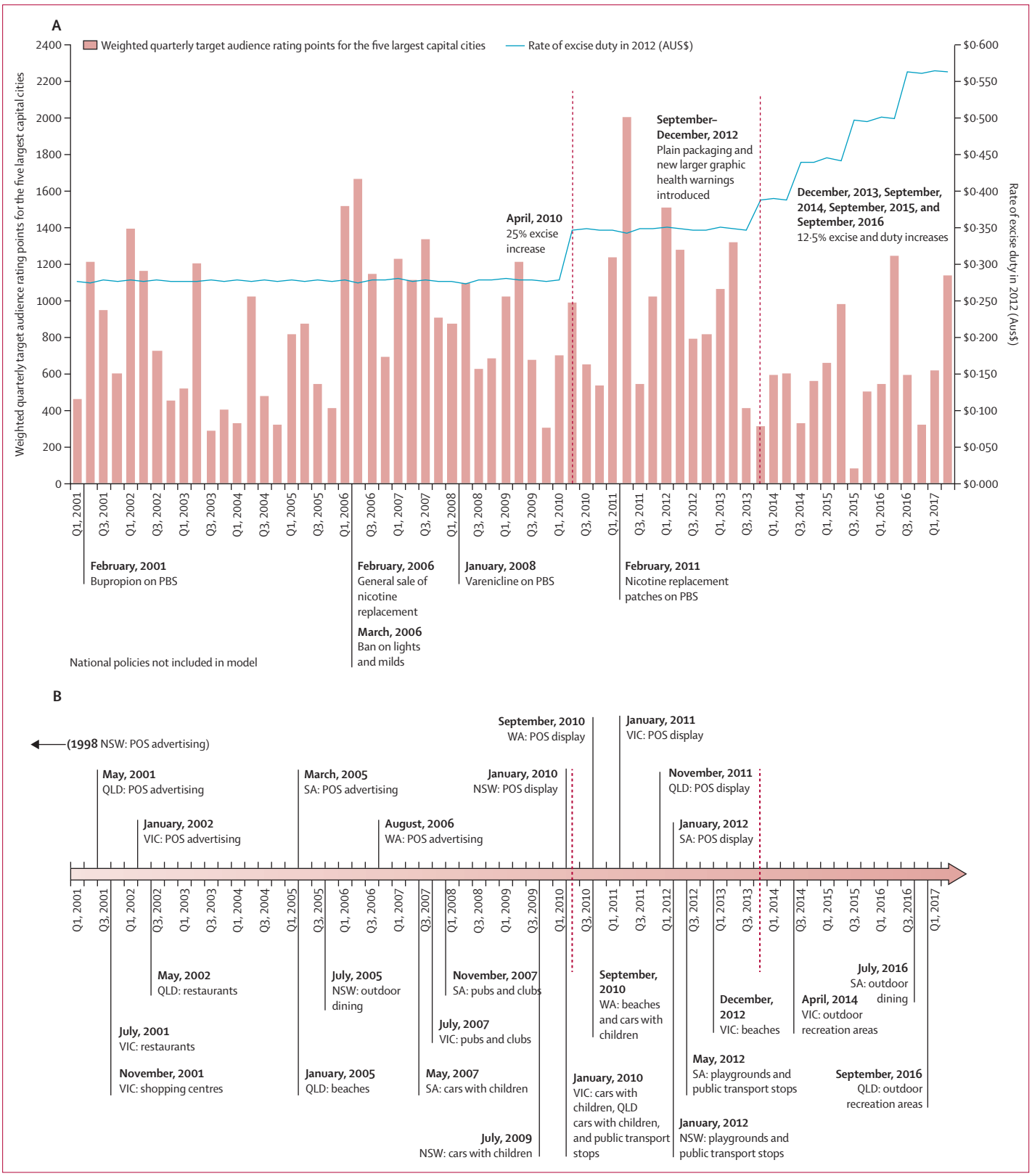
Implications of all the available evidence

Large tobacco tax increases should be considered by all countries as a priority, and they are important for reducing tobacco-related disparities. Both unannounced large tax increases and pre-announced, staged substantive increases in taxes can be immediately effective in reducing the prevalence of smoking. Pre-announced, staged substantive increases might be more effective over time in reducing smoking prevalence than one-off unannounced large tax increases. To maximise the effectiveness of increases in tobacco taxes and to reduce product substitution, nations should structure taxes so that roll-your-own (loose) tobacco product prices increase in line with price increases in factory-made cigarettes. Standardisation of pack and pouch size and use of minimum prices would reduce the ability of tobacco companies to market products that are cheaper upfront, or which otherwise lessen the impact of or confuse price signals after tax increases.

Tax policy has taken a comparable course in New Zealand, which has similarly advanced tobacco control and where a 10% increase in tobacco tax was implemented without forewarning in April, 2010. This tax increase was followed by a series of pre-announced 10% annual increases.[8] Phone calls to the New Zealand Quitline service increased after the 2010 and 2011 10% tax increases.[14] Increases in quit attempts were detected by self-report data from telephone surveys after the 2012 tax increase, the third in the series, which represented a 14·5% increase (ie, a 10% real-tax increase plus indexation).[14] A 3-month before-and-after study[15] of the 2014 and 2015 10% increases found small changes to smoking behaviours (ie, quitting, quitting attempts, and reductions in smoking) following those increases, leading some to conclude that the tax increases were no longer effective. However, the authors noted that the proportion of respondents making quit attempts were increased in the 3 months before each increase, and that the proportion of respondents making quit attempts was greater than that reported after the 2012 increase. The findings in New Zealand are consistent with predictions of economic theories of addiction[16,17] that highlight the impact of changes in anticipated future costs as one of the determinants of current smoking, and with empirical studies[18,19] showing that smokers make attempts to quit in anticipation of tax increases. Among Australian smokers, increases in quit attempts were detected after the 2010 25% tax increase, but the study[20] was only done within one jurisdiction and, similarly to the New Zealand study, was restricted to several months either side of the intervention. Furthermore, these studies only examined changes among current smokers, whereas tax increases

***Figure 1*: Timelines of tax and non-tax related tobacco control measures introduced in Australia from January, 2001, to April, 2017**

(A) Model included national-level policies, such as increases in excise duty (interruption points), target audience ratings points from tobacco control mass-media campaigns, and plain packaging introduction, but it excluded change in the availability of smoking cessation medications and a ban on cigarettes being described as lights and milds. (B) Model also excluded the introduction of various non-national policy changes (state-level point-of-sale advertising and display bans and smoke-free air laws). PBS=Pharmaceutical Benefits Scheme. POS=point-of-sale.


A
Weighted quarterly target audience rating points for the five largest capital cities
Rate of excise duty in 2012 (AUS$)
Weighted quarterly target audience rating points for the five largest capital cities
Rate of excise duty in 2012 (Aus$)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
$0·600
$0·550
$0·500
$0·450
$0·400
$0·350
$0·300
$0·250
$0·200
$0·150
$0·100
$0·050
$0·000
Q1, 2001
Q3, 2001
Q1, 2002
Q3, 2002
Q1, 2003
Q3, 2003
Q1, 2004
Q3, 2004
Q1, 2005
Q3, 2005
Q1, 2006
Q3, 2006
Q1, 2007
Q3, 2007
Q1, 2008
Q3, 2008
Q1, 2009
Q3, 2009
Q1, 2010
Q3, 2010
Q1, 2011
Q3, 2011
Q1, 2012
Q3, 2012
Q1, 2013
Q3, 2013
Q1, 2014
Q3, 2014
Q1, 2015
Q3, 2015
Q1, 2016
Q3, 2016
Q1, 2017
April, 2010
25% excise increase
September–December, 2012
Plain packaging and new larger graphic health warnings introduced
December, 2013, September, 2014, September, 2015, and September, 2016
12·5% excise and duty increases
February, 2001
Bupropion on PBS
February, 2006
General sale of nicotine replacement
March, 2006
Ban on lights and milds
January, 2008
Varenicline on PBS
February, 2011
Nicotine replacement patches on PBS
National policies not included in model
B
(1998 NSW: POS advertising)
May, 2001
QLD: POS advertising
January, 2002
VIC: POS advertising
March, 2005
SA: POS advertising
August, 2006
WA: POS advertising
January, 2010
NSW: POS display
September, 2010
WA: POS display
January, 2011
VIC: POS display
November, 2011
QLD: POS display
January, 2012
SA: POS display
May, 2002
QLD: restaurants
July, 2005
NSW: outdoor dining
November, 2007
SA: pubs and clubs
September, 2010
WA: beaches and cars with children
December, 2012
VIC: beaches
April, 2014
VIC: outdoor recreation areas
July, 2016
SA: outdoor dining
July, 2001
VIC: restaurants
November, 2001
VIC: shopping centres
January, 2005
QLD: beaches
May, 2007
SA: cars with children
July, 2007
VIC: pubs and clubs
July, 2009
NSW: cars with children
January, 2010
VIC: cars with children, QLD cars with children, and public transport stops
May, 2012
SA: playgrounds and public transport stops
January, 2012
NSW: playgrounds and public transport stops
September, 2016
QLD: outdoor recreation areas

could also reduce prevalence by reducing youth uptake and helping ex-smokers to avoid relapse.

To our knowledge, no published empirical studies have assessed the immediate and longer-term effects of very large and differently structured tax increases on the prevalence of smoking in a single nation. Challenges to observing the effect of tax increases include confounding by other tobacco control policies and the possibility of a secular trend of decreasing smoking prevalence that is not directly related to policy interventions. An interrupted time-series analysis is an approach that can account for both confounding and the underlying trend in a data series.[21] Time-series analyses have previously been used to examine the effects of tobacco tax interventions in the USA[22] and media campaigns in Australia.[23] This approach is well suited to examining Australia's tobacco tax increases because these were applied nationally, at known timepoints.

By use of a unique data series of population-level monthly smoking prevalence over several decades, we aimed to examine immediate and longer-term effects of Australia's two major tobacco tax interventions, in 2010 and starting from 2013, on smoking prevalence. We proposed that large tobacco tax increases would have an immediate effect on smoking prevalence, and we aimed to explore any sustained effects associated with each of the interventions. We also expected greater effects on smokers from lower socioeconomic groups, although we expected that these effects would be somewhat mitigated by industry response to tobacco control interventions.

Methods

Study design and participants

We did an ecological study of the effects of increases in tobacco tax on monthly smoking prevalence using time-series data. We did our analysis at the national level—for the whole population—and for socioeconomic subgroups.

Roy Morgan Research, a market research company, supplied data from an omnibus survey that used a consistent method among Australians aged 14 years or older. We used data collected in five of Australia's major capital cities (Sydney, Melbourne, Brisbane, Perth, and Adelaide). To capture a representative sample, the company used a multistage sampling strategy to split cities into areas of approximately equal population size and then divided areas into segments. Beginning from a randomly selected address, households within segments were systematically approached and data were collected on weekends. Interviewers were instructed to recruit one person per household, asking first for the youngest male and, if unavailable, then for the youngest female. Approximately 30% of those approached responded to the survey. The survey included questions on current smoking behaviours, such as "[d]o you now smoke factory-made cigarettes?" and "[i]n the last month, have you smoked any roll-your-own [tobacco] cigarettes?"

Procedures

We were interested in the effects of two tax-related interventions. First, we aimed to evaluate the effects of the 25% increase in tobacco taxes imposed by the Australian Government overnight on April 30, 2010 (from which the tax on cigarettes increased from AUS$0·2622 to $0·3278 per cigarette). Second, we wanted to evaluate the effects of the series of four 12·5% annual increases in tobacco taxes, which commenced on Dec 1, 2013 (from $0·3573 to $0·4020 per cigarette).[24] This second intervention differed from the first in that it was announced in advance (in August, 2013, and again in November, 2013), and the announcements included the advice that three subsequent 12·5% increases would occur (in September, 2014, September, 2015, and September, 2016). By September, 2016, the tobacco tax was $0·6105 per cigarette.[24] There were insufficient months between the annual tobacco tax increases to allow testing of each as an interruption, so we considered the beginning of this intervention—December, 2013 (the date from which the package of four increases was implemented)—as the interruption to be tested.

Outcomes

Our primary outcome was smoking prevalence, aggregated to a monthly level. Data were weighted for non-response based on age, sex, and city to provide representative monthly estimates of smoking prevalence. Prevalence was calculated for overall smoking (factory-made cigarettes [FMC], or roll-your-own tobacco [RYO], or both), any FMC, and any RYO. The denominator for all three prevalence outcomes was the estimated population in the five capital cities, in which two-thirds of the Australian population resides.[25]

We conducted sensitivity analyses of two alternative options for operationalising the December, 2013, interruption; first, we modelled August, 2013 (the month during which the policy was first announced) as the interruption and, second, we modelled November, 2013 (the month before the anticipated increase, when the Government made a reminder announcement of the policy) as the interruption.

Statistical analysis

We employed an interrupted time-series analysis, accounting for autocorrelation among monthly observations by fitting Prais-Winsten linear regression models, which were estimated using generalised least-squares estimation with robust standard errors.[26] We commenced the data series in May, 2001, 10 years before the first tax increase. The first segment of the data covered a period of only-inflation adjustment, with no real increases in tobacco tax. Because the Government announced another series of four 12·5% tobacco tax increases in May, 2017 (to commence in September, 2017),[27] we ended the series for this analysis in April, 2017, the month before the announcement. The segments modelled were May, 2001,

to April, 2010 (before the tax increase; segment A), May, 2010, to November, 2013 (the 25% tax increase; segment B), and December, 2013, to April, 2017 (the series of four annual 12·5% tax increases; segment C).

The model estimated several coefficients: the slope before the intervention (an estimate representing the average monthly change in prevalence over the first study period—from May, 2001, to April, 2010—referred to as the pre-tax trend), which included the months up to the intervention; the slope after the intervention, which started at the month of the intervention (the post-tax trend); and the difference between these slopes. Our model also estimated the change in the level of these slopes (the immediate effect) at the intervention month. The immediate effect is the difference between the expected value (mean) predicted by the model that included the interruption and the expected value with no intervention, at the intervention month (ie, the predicted prevalence in May, 2010, given the intervention, minus predicted prevalence at May, 2010, as if no tax had occurred). Further detail on the rationale for the analytic model, model specification, assumption testing, and model fit testing is shown in the appendix (pp 4–5).

Our models were consistent with recommendations for conducting interrupted time-series analysis with covariates,[21] and they were adjusted for tobacco control policies that were either time-varying or global (ie, a national intervention) and that occurred relatively close to an interruption being tested and could potentially account for some of the effect of the intervention. Time-varying covariates included tobacco tax indexation and mass media campaigns.

In preliminary analyses, we tested for seasonality by including a categorical month-of-year variable, with January as the reference category. We found no seasonality in any months. Tobacco tax is indexed biannually in Australia. Our previous research[11] suggested that, between 2001 and 2013, the tobacco industry increased prices in excess of the indexation in February but not in August, and these February increases contributed to a reduction in smoking prevalence. From 2014, the basis of indexation of the tobacco tax was changed from prices to wages, and indexation was moved from February and August to March and September, to align with the timing of release of official data on second-quarter and fourth-quarter average weekly earnings. British American Tobacco Australasia, representing two-thirds of the Australian market, continued to increase prices in February[28] rather than moving to increases in line with the new indexation month (March). To account for these cyclical price increases that continued in February throughout the period of study, we included an indicator variable for February for 2001–17.

Governments invested in tobacco control mass media campaigns to variable extents over the study period, providing a second time-varying covariate. Target-audience rating points (TARPs) for adults aged 18 years and older provide an estimate of television advertising exposure (calculated as population reach multiplied by frequency), such that 100 TARPs can equate to an average of one potential advertisement exposure per month among 100% of adults. TARPs for each capital city were aggregated and population-weighted for a national-level analysis. TARPs were included as a continuous variable, with a 2-month lag.[29]

15 months before the tobacco tax increase in December, 2013, tobacco plain packaging was implemented nationally; this initiative was previously shown to have reduced smoking prevalence by about 0·50–0·56 percentage points after adjusting for the tax increases in 2010, 2013, and 2014,[30] and so it was important that the implementation of plain packaging be included as a covariate. Any tobacco products manufactured from September, 2012, had to be in plain packaging, and retailers could only sell plainly packaged products from December, 2012. The implementation effect of plain packaging was therefore modelled as 0 for months up to and including September, 2012, 1 for October, November, and December, 2012, and 0 thereafter.

Roy Morgan Research also provided a socioeconomic quintiles variable, which was calculated using self-reported income, the highest level of education obtained, and current occupation. We aggregated the quintiles into a binary variable: higher socioeconomic status (SES; the top three quintiles) and lower SES (the lower two quintiles). Smoking prevalence within these SES categories closely aligns with prevalence estimates from government-funded triennial National Drug Strategy Household surveys[31] (appendix p 1), providing confidence they are representative.

See Online for appendix

Effect modification by SES for each immediate effect, each segment trend, and each difference between segment trends was tested using SES×tax×time interactions. After we found evidence of effect modification (appendix p 3), we proceeded to stratified models, to test and present within-strata effects. We reported unadjusted and adjusted models for smoking prevalence for the overall sample for any smoking (FMC, or RYO, or both), any FMC use, and any RYO use, and adjusted models for these smoking groups within higher SES and lower SES strata.

Role of the funding source

The funder of the study had no role in the study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Outcome data were collected between May 1, 2001, and April 30, 2017. Over the study period, tobacco excise duty increased from $0·203 to $0·617 per cigarette weighing less than 0·8 g. The value of the duty in constant terms ($ value in 2012) approximately doubled over the 16-year period (figure 1).

	Segment A trend (May, 2001, to April, 2010)	25% increase in customs and excise duty from April 30, 2010			Series of pre-announced 12·5% annual increases from Dec 1, 2013				Model fit, R^2 (AIC)
		Level change in May, 2010, vs level without tax intervention	Segment B trend (May, 2010, to November, 2013)	Difference in trends (segment B–segment A)	Level change in December, 2013, vs level without tax intervention	Segment C trend (December, 2013, to April, 2017)	Difference in trends (segment C–segment B)	Difference in trends (segment C–segment A)	
Unadjusted									
FMC, or RYO, or both	–0·039 (–0·045 to –0·033)	–0·809 (–1·424 to –0·194)	–0·026 (–0·046 to –0·007)	0·013 (–0·008 to 0·033)	–0·804 (–1·397 to –0·212)	–0·045 (–0·063 to –0·026)	–0·018 (–0·045 to 0·009)	–0·006 (–0·025 to 0·014)	0·896 (501·035)
Any FMC	–0·038 (–0·044 to –0·032)	–1·072 (–1·605 to –0·538)	–0·023 (–0·041 to –0·005)	0·015 (–0·004 to 0·034)	–0·755 (–1·375 to –0·136)	–0·055 (–0·072 to –0·038)	–0·032 (–0·057 to –0·007)	–0·017 (–0·034 to 0·001)	0·912 (484·698)
Any RYO	–0·009 (–0·012 to –0·005)	0·069 (–0·0239 to 0·377)	0·016 (0·008 to 0·024)	0·025 (0·016 to 0·034)	–0·251 (–0·636 to 0·134)	0·002 (–0·013 to 0·018)	–0·014 (–0·031 to 0·004)	0·011 (–0·005 to 0·027)	0·171 (284·628)
Adjusted*									
FMC, or RYO, or both	–0·039 (–0·045 to –0·034)	–0·745 (–1·378 to –0·112)	–0·023 (–0·044 to –0·003)	0·016 (–0·005 to 0·038)	–0·997 (–1·632 to –0·362)	–0·044 (–0·063 to –0·026)	–0·021 (–0·049 to 0·007)	–0·005 (–0·024 to 0·015)	0·898 (501·618)
Any FMC	–0·039 (–0·044 to –0·033)	–1·005 (–1·564 to –0·446)	–0·020 (–0·040 to –0·0001)	0·019 (–0·002 to 0·039)	–0·945 (–1·616 to –0·274)	–0·054 (–0·071 to –0·038)	–0·034 (–0·060 to –0·009)	–0·016 (–0·033 to 0·001)	0·914 (482·623)
Any RYO	–0·009 (–0·012 to –0·005)	0·074 (–0·236 to 0·384)	0·018 (0·010 to 0·025)	0·027 (0·018 to 0·035)	–0·324 (–0·704 to 0·056)	0·002 (–0·014 to 0·018)	–0·016 (–0·033 to 0·002)	0·011 (–0·005 to 0·027)	0·185 (287·467)

Data are β-coefficients (95% CIs) from the linear regression model. FMC=factory-made cigarettes. RYO=roll-your-own tobacco. AIC=Akaike information criteria. *Models adjusted for implementation of plain packs (October–December, 2012), reach of the mass-media quit smoking campaigns (monthly target audience rating points at lag two), indexation of excise and customs duty from February, 2002, to February, 2014, and retail price increases from February, 2015, to February, 2017. Both models accounted for autocorrelation and used robust standard errors to account for repeated measures.

Table 1: **Interrupted time-series analysis of monthly smoking prevalence and two tax interventions (interruptions) from May, 2001, to April, 2017 (192 months), in Australians aged 14 years and older who resided in one of five capital cities**

480 815 participants completed surveys during the study period. Unadjusted and adjusted estimates of smoking prevalence for the overall sample (by smoking groups) are shown in table 1. Estimates of smoking prevalence from the unadjusted models are also shown in figure 2 (overall sample) and figure 3 (by smoking group). Overall prevalence of smoking decreased from 22·6% in May, 2001, to 12·8% in April, 2017, which represented a 43·4% relative reduction. Over the study period, smoking prevalence decreased from 20·3% to 9·6% among people with higher SES and from 26·7% to 18·2% among those with lower SES (data not shown).

The adjusted model showed decreased smoking prevalence in the period before the 25% tobacco tax increase (table 1). The 25% increase in customs and excise duty was associated with an immediate reduction in prevalence of –0·745 percentage points (95% CI –1·378 to –0·112), which was driven by a reduction in the prevalence of smoking of any FMC. This absolute reduction in smoking prevalence was equivalent to a relative reduction in overall smoking prevalence of 4·2%. In the period after the 25% increase and before the next tax intervention (December, 2013), the prevalence of smoking of any FMC continued to decrease at a rate similar to the trend before the introduction of the 25% tax, but the prevalence of smoking of any RYO increased, in contrast with the decreasing trend before the introduction of the 25% tax. The net effect was a modest continuing decrease in overall smoking prevalence at a rate of –0·023 percentage points per month (95% CI –0·044 to –0·003), which was similar to that before the introduction of the 25% tax (difference in trends between segments B and A 0·016; 95% CI –0·005 to 0·039).

The first of the four 12·5% increases in tobacco tax was associated with an immediate prevalence reduction of –0·997 percentage points (95% CI –1·632 to –0·362), which was driven by reductions in the prevalence of smoking of any FMC (table 1). This reduction in smoking prevalence was equivalent to a 6·2% relative reduction in overall smoking prevalence. In the 3·5 years of annual increases following the first 12·5% increase, the prevalence of smoking continued to decrease at a rate similar to that before and after the introduction of the 25% tax. The prevalence of smoking of any FMC decreased at a faster rate per month over this period of annual tax increases than it did after the 25% increase, but this rate did not differ from the trend before the 25% tax increase. The trend of an increase in the prevalence of smoking of any RYO that was observed between May, 2010, and November, 2013, ceased during the period of annual 12·5% increases, and the trend did not significantly differ relative to that before the introduction of the 25% tax increase (difference in trends between segment A and C 0·011, 95% CI –0·005 to 0·027).

The effects of the 25% tax increase differed by SES (appendix p 3). We observed a substantial immediate

overall decrease in smoking prevalence among the lower SES group but only a modest decrease among the higher SES group (table 2). The prevalence of smoking of any RYOs immediately increased in the higher SES group but not in the lower SES group. The difference between the trends before and after the 25% increase in tobacco tax for overall smoking prevalence and the prevalence of smoking of any RYO also differed by SES. After the 25% tax increase, the overall prevalence decreased in the higher SES group at a similar rate to that before the 25% tax increase. The trend after the 25% tax increase was flatter than the before-tax trend among lower SES groups. We observed no ongoing increases in use of any RYO among the higher SES groups. By contrast, among the lower SES group, the prevalence of smoking of any RYO increased between May, 2010, and November, 2013, which was different to the trend observed before the 25% tax increase.

Following the first of the 12·5% increases, we observed differential immediate effects on overall prevalence by SES (appendix p 3), with substantial immediate reductions in overall smoking prevalence among the lower but not higher SES group (table 2). Sustained reductions in overall prevalence were observed in the higher SES group, which were driven by a decreasing prevalence of smoking of any FMC between December, 2013, and April, 2017, at a rate that was steeper than the trend before the 25% tax increase. Among the lower SES group, there was also a sustained reduction in the prevalence of smoking of any FMC over the subsequent 3·5-year period of annual tax increases until April, 2017, which was steeper than the previous period and did not significantly differ relative to the decreasing trend before the 25% tax increase. The trends in prevalence of smoking of any RYO after the start of the annual 12·5% tax intervention also differed by SES, since the previous increasing trend in the prevalence of smoking of any RYO among lower SES groups was halted.

Sensitivity analyses that compared the interruption in December, 2013, to an interruption in August, 2013 (ie, the first announcement of the series of four tax increases) and to an interruption in November, 2013 (the second announcement and the month before implementation) found no difference relative to the interruption in May, 2010 (appendix p 2). Comparing the three models, the largest immediate reduction was detected with an interruption in December, 2013. The estimated immediate reduction was lower in magnitude when November, 2013, was considered to be the interruption, and the reduction was no longer significantly different relative to the same period under the condition of no tax intervention with August, 2013, considered to be the interruption.

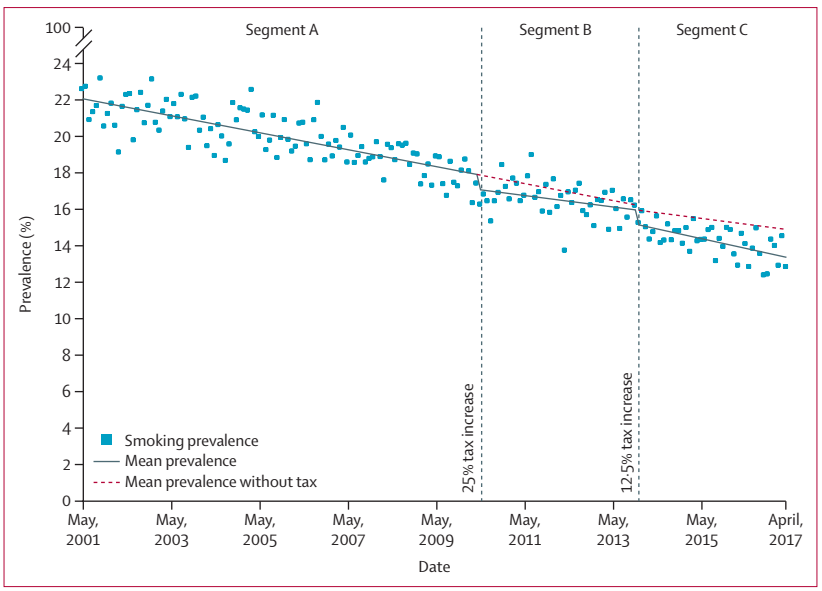


Figure 2: **Month-level overall smoking prevalence in Australians aged 14 years and older residing in one of five capital cities between May, 2001, and April, 2017**
Data are as observed and predicted from an unadjusted interrupted time-series analysis. Red line shows predicted prevalence if taxes were not introduced.

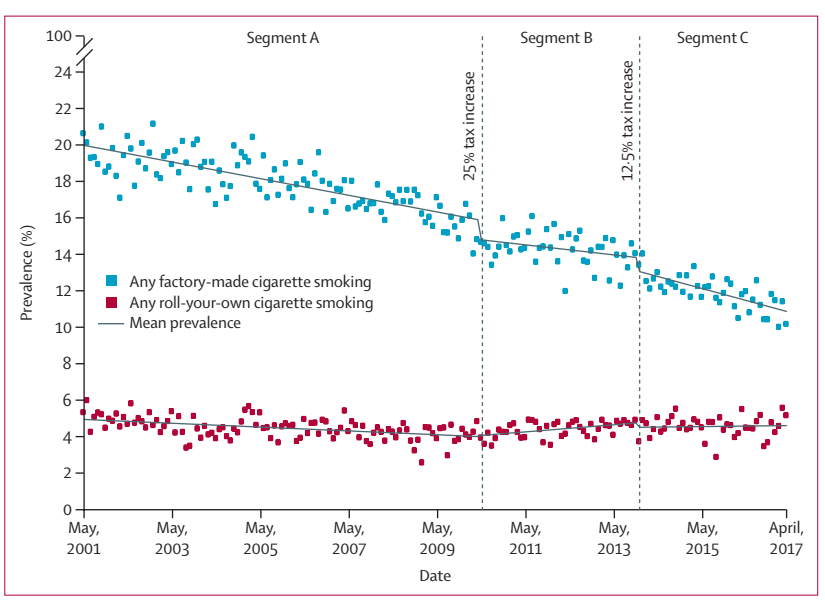


Figure 3: **Month-level prevalence of smoking of factory-made and roll-your-own cigarettes in Australians aged 14 years and older residing in one of five capital cities between May, 2001, and April, 2017**
Data are as observed and predicted from unadjusted interrupted time-series analysis.

Discussion

By use of 16 years of monthly time-series data, we examined the effects of Australia's two major tobacco tax interventions between May 2001, and April, 2017. We observed a consistent decreasing trend of smoking prevalence and immediate large percentage-point reductions in prevalence associated with the introduction of these two tax interventions. However, the immediate and longer-term responses across the two interventions differed by tobacco type and SES group.

Although our study provides evidence on the effectiveness of two novel tax interventions that differed

	Segment A trend (May, 2001, to April, 2010)	25% increase in customs and excise duty from April 30, 2010			Series of pre-announced 12·5% annual increases from Dec 1, 2013				Model fit, R^2
		Level change in May, 2010, *vs* level without tax intervention	Segment B trend (May, 2010, to November, 2013)	Difference in trends (segment B–segment A)	Level change in December, 2013, *vs* level without tax intervention	Segment C trend (December, 2013, to April, 2017)	Difference in trends (segment C–segment B)	Difference in trends (segment C–segment A)	
High socioeconomic status									
FMC, or RYO, or both	−0·045 (−0·052 to −0·039)	−0·275 (−1·150 to 0·600)	−0·044 (−0·072 to −0·016)	0·001 (−0·027 to 0·030)	−0·434 (−1·188 to 0·319)	−0·058 (−0·082 to −0·034)	−0·014 (−0·051 to 0·022)	−0·013 (−0·038 to 0·012)	0·879
Any FMC	−0·044 (−0·051 to −0·038)	−0·671 (−1·392 to 0·051)	−0·035 (−0·059 to −0·012)	0·009 (−0·015 to 0·034)	−0·379 (−1·060 to 0·302)	−0·065 (−0·087 to −0·046)	−0·031 (−0·062 to 0·000)	−0·022 (−0·044 to −0·001)	0·903
Any RYO	−0·009 (−0·013 to −0·006)	0·379 (0·015 to 0·743)	0·002 (−0·008 to 0·012)	0·001 (0·0003 to 0·022)	−0·179 (−0·687 to 0·328)	−0·0002 (−0·018 to 0·018)	−0·002 (−0·022 to 0·019)	0·009 (−0·009 to 0·028)	0·151
Low socioeconomic status									
FMC, or RYO, or both	−0·029 (−0·039 to −0·020)	−1·633 (−2·615 to −0·650)	0·022 (−0·008 to 0·052)	0·052 (0·021 to 0·083)	−2·328 (−3·516 to −1·140)	−0·023 (−0·058 to 0·013)	−0·045 (−0·091 to 0·001)	0·007 (−0·030 to 0·044)	0·669
Any FMC	−0·029 (−0·039 to −0·019)	−1·657 (−2·643 to −0·672)	0·014 (−0·018 to 0·047)	0·044 (0·010 to 0·078)	−2·266 (−3·433 to −1·100)	−0·037 (−0·069 to −0·005)	−0·051 (−0·097 to −0·005)	−0·007 (−0·041 to 0·026)	0·728
Any RYO	−0·008 (−0·014 to −0·002)	−0·537 (−1·076 to 0·002)	0·050 (0·033 to 0·067)	0·058 (0·040 to 0·076)	−0·658 (−1·312 to −0·005)	0·007 (−0·016 to 0·030)	−0·043 (−0·071 to −0·015)	0·015 (−0·009 to 0·039)	0·185

Data are β-coefficients (95% CIs) from the linear regression model. Models were adjusted for implementation of plain packs (October–December, 2012), reach of the mass-media quit smoking campaigns (monthly target audience rating points at lag two), indexation of excise or customs duty from February, 2002, to February, 2014, and retail price increases from February, 2015, to February, 2017. Both models accounted for autocorrelation and used robust standard errors to account for repeated measures. FMC=factory-made cigarettes. RYO=roll-your-own tobacco.

Table 2: **Interrupted time-series analysis of monthly smoking prevalence and two tax interventions (interruptions) from May, 2001, to April, 2017 (192 months), in Australians aged 14 years and older who resided in one of five capital cities, by socioeconomic subgroups**

markedly in forewarning and whether they were one-off versus a series of increases, our study does not offer a definitive head-to-head comparison, since the second intervention built upon the first and was larger in overall magnitude. The similar size of the immediate effect on overall prevalence and the prevalence of smoking of any FMC observed in December, 2013 (after a 12·5% increase) compared with May, 2010 (after the 25% increase) could reflect the effects of forewarning smokers about the steepening taxes that were to confront smokers in future years (a 40% rise in tobacco tax, in real terms).[5] Our finding is consistent with predictions of economic theories of addiction that highlight the impact of changes in anticipated future costs as one of the determinants of current smoking.[16,17] In our model, the introduction of the four annual tax changes appeared to have an immediate impact on current smoking, which we interpret as resulting from the reality of the first increase and also from the anticipation of subsequent tax and price increases. The ongoing decrease in smoking observed after December, 2013, similarly, is consistent not just with the longer-term effects of the December, 2013, tax increase and the immediate and longer-term effects of a further three annual 12·5% tax increases, but also with ongoing anticipation of each of those increases.

The decreasing trend in the prevalence of smoking of any FMC after 2013 was steeper than that after 2010, but the trend was similar to the May, 2001–April, 2010, trend, during which time prevalence reductions were driven by several tobacco control policies,[29] including state-level restrictions on promotion of tobacco products at the point of sale and rapidly widening restrictions on smoking in public places. This finding suggests that, in addition to the immediate effects at introduction, the second tax policy intervention provided ongoing downward pressure on prevalence at a magnitude similar to that of the combined effects of the more comprehensive and frequent non-tax related policy changes that occurred in Australia before April, 2010 (figure 1).

We found evidence that suggested smokers engaged in product switching from FMC to RYO in the years after the 25% tax intervention, with ongoing increases in the prevalence of smoking any RYO and ongoing decreases in the prevalence of smoking any FMC, although, nonetheless, the net effect was a small overall decrease in prevalence. The tobacco industry in Australia has increasingly pursued price marketing strategies, including a wider range of RYO products, new small pack and pouch sizes, bonus cigarettes, and so-called super-value brands. These strategies provided more options to avoid large increases in upfront costs in the years following the 25% tobacco tax increase.[32]

Notably, the lower SES group responded more rapidly and to a greater extent to the 25% tax intervention than the higher SES group. However, subsequent increases in the prevalence of smoking of RYO among the lower but not higher SES group suggests more pronounced longer-term product switching to RYO, consistent with evidence of

greater price sensitivity among low-income groups.[3,5] The prevalence of smoking of RYO decreased immediately among the lower SES group at the time of the December, 2013, tax intervention and, from this time until April, 2017, did not continue to increase, whereas the prevalence of smoking of any FMC also decreased more rapidly and to a greater extent among lower SES groups than higher SES groups, and the prevalence of smoking of any FMC continued to decrease in both SES groups. Many smokers might have already switched to RYO and other low-priced options after the 25% tax increase and, with each subsequent 12·5% annual increase, they might have increasingly had no other options but to quit.

Our study was restricted by a paucity of data on the prices charged for tobacco products at the retail level. Industry strategies to maintain tobacco product affordability might have protected consumers from the impact of scheduled tax increases by gradually increasing prices over time or increasing the prices of premium products more than the prices of budget products. No data are publicly available in Australia on tobacco prices, sales volumes, or product market share. However, a strength of our study was that we used monthly survey data from a high-quality, representative sample of the population on the prevalence of use of RYO and FMC in the years before and after each tax intervention. This approach provided a sample that was large enough to detect changes in smoking prevalence overall and among certain population groups. Although questions about any use of FMC and RYO were asked using different wording, these questions were consistent over the years of the survey. Our study was observational and ecological in nature, and so we had no control group; however, our robust study design allowed us to evaluate the effect of tobacco tax increases while accounting for underlying trends and key covariates where possible.

Our study suggests that large tax increases are effective in reducing overall smoking prevalence, and that such increases are strongly and immediately effective among those in lower SES groups. Our findings indicate that staged increases that confront smokers with a substantial steepening of cost over several years could be more effective in sustaining changes in smoking prevalence than one-off increases, and that taxes need to be structured so that RYO products are not substantially cheaper than FMC. Such harmonisation is particularly important from an equity perspective, to prevent switching or relapse to cheaper products over time among those in lower SES groups. Standardisation of pack and pouch size, bans on other forms of price-related marketing, restrictions on the frequency of price changes and, perhaps, use of minimum prices would reduce the ability of tobacco companies to market products that are cheaper upfront or that otherwise lessen the impact of or confuse price signals after tax increases.[33] Tobacco taxation policy should be protected against industry price marketing strategies and complemented by other tobacco control policies to maximise value for tobacco control investment.

Contributors

ALW cleaned and managed the data, executed the analysis, prepared the manuscript (including the tables and figures), and drafted and edited the manuscript. MMS, MAW, and SJD defined the research question and acquired the data. MMS, MAW, MJS, FJC, and SJD reviewed the data analyses, interpreted the data, and reviewed and edited the manuscript.

Declaration of interests

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