Association between electronic cigarette use and changes in quit attempts, success of quit attempts, use of smoking cessation pharmacotherapy, and use of stop smoking services in England: time series analysis of population trends

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ABSTRACT

OBJECTIVES

To estimate how far changes in the prevalence of electronic cigarette (e-cigarette) use in England have been associated with changes in quit success, quit attempts, and use of licensed medication and behavioural support in quit attempts.

DESIGN

Time series analysis of population trends.

PARTICIPANTS

Participants came from the Smoking Toolkit Study, which involves repeated, cross sectional household surveys of individuals aged 16 years and older in England. Data were aggregated on about 1200 smokers quarterly between 2006 and 2015. Monitoring data were also used from the national behavioural support programme; during the study, 8 029 012 quit dates were set with this programme.

SETTING

England.

MAIN OUTCOME MEASURES

Prevalence of e-cigarette use in current smokers and during a quit attempt were used to predict quit success. Prevalence of e-cigarette use in current smokers was used to predict rate of quit attempts. Percentage of quit attempts involving e-cigarette use was also used to predict quit attempts involving use of prescription treatments, nicotine replacement therapy (NRT) on prescription and bought over the counter, and use of behavioural support. Analyses involved adjustment for a range of potential confounders.

RESULTS

The success rate of quit attempts increased by 0.098% (95% confidence interval 0.064 to 0.132; P<0.001) and 0.058% (0.038 to 0.078; P<0.001) for every 1% increase in the prevalence of e-cigarette use by smokers and e-cigarette use during a recent quit attempt, respectively. There was no clear evidence for an association between e-cigarette use and rate of quit attempts (β 0.025; 95% confidence interval −0.035 to 0.085; P=0.41), use of NRT bought over the counter (β 0.006; −0.088 to 0.077; P=0.89), use of prescription treatment (β −0.070; −0.152 to 0.013; P=0.10), or use of behavioural support (β −0.013; −0.102 to 0.077; P=0.78). A negative association was found between e-cigarette use during a recent quit attempt and use of NRT obtained on prescription (β −0.098; −0.189 to −0.007; P=0.04).

CONCLUSION

Changes in prevalence of e-cigarette use in England have been positively associated with the success rates of quit attempts. No clear association has been found between e-cigarette use and the rate of quit attempts or the use of other quitting aids, except for NRT obtained on prescription, where the association has been negative.

STUDY REGISTRATION

The analysis plan was preregistered (https://osf.io/fbgj2/).

WHAT IS ALREADY KNOWN ON THIS TOPIC

There are concerns that the increase in population use of electronic cigarettes could be undermining smoking cessation

If true, e-cigarettes could have a negative effect on public health

WHAT THIS STUDY ADDS

This empirical study used a time series approach to estimate the population impact of e-cigarettes on attempts to quit smoking and their success, on the use of smoking cessation pharmacotherapy, and on the use of stop smoking services in England

The study findings conflict with the hypothesis that an increase in population use of e-cigarettes undermines quitting, but it may have reduced the use of nicotine replacement therapy obtained on prescription and be positively associated with quit success

Introduction

There has been concern that the increase in population use of electronic cigarettes (e-cigarettes) could be undermining quitting activities.[1-7] If this is true, then e-cigarettes could have a negative effect on public health, even if they might increase the chances of success for an individual smoker using them in a given quit attempt.[8 9] England is a country with a relatively liberal regulatory framework for e-cigarettes and has seen a considerable growth in their use.[10 11] It also has unique time series data to be able to estimate changes over time in key quitting activities as a function of changes in prevalence of e-cigarette use while adjusting for other potential confounding variables.[10 12] This study used data from England to address the concerns that have been raised.

One source of concern about the potential impact of e-cigarettes on quitting activity arises from a fall in the use of licensed treatments and behavioural support programmes in England to stop smoking.[10 13] This may be a result of smokers using e-cigarettes instead.[14-16] However, the decrease could also be due to other factors or a secular trend unconnected to the rise in e-cigarette use. In a related study, we found that the increase in population rates of e-cigarette use while smoking was probably not responsible for a decline in use of nicotine replacement therapy (NRT) for smoking reduction.[10]

It has also been proposed that smokers who currently use or have used e-cigarettes in the past are less likely subsequently to quit smoking.[1-7] However, data on the

prevalence of e-cigarette use in quit attempts—combined with evidence from randomised controlled trials and a real world effectiveness study suggesting that e-cigarettes are about as effective as NRT obtained on prescription[8 9 17-20]—leads to an estimate of an additional 16 000-22 000 ex-smokers created each year from the use of e-cigarettes in England.[21] If e-cigarette use is harming or promoting smoking cessation in a population, it should be possible to observe an association between changes in e-cigarette use over time and changes in quit attempts and successful quit attempts, adjusting for potential confounding variables in the population such as tobacco control policies. This would provide a direct estimate of the public health impact of the rise in e-cigarette use.

Time series analysis of population trends affords this ability by directly estimating the population level impact of policies and events. Where associations are found, they cannot establish a causal association but can be indicative. For example, these associations have been used to estimate the effect of price of cigarettes on population consumption, mass media expenditure on use of specialist stop smoking services, and introduction of varenicline to the market on the prevalence of use of smoking cessation treatment.[22-24] If associations are not found, or they go in a direction opposite to that expected, this can also be informative.

Therefore, this study aimed to assess, using time series analysis, whether changes in e-cigarette use at a population level have been associated with changes in key smoking cessation activities and use of licensed smoking cessation treatment. More specifically, we were interested in:

- The association between success rates of individuals who made a quit attempt in the past 12 months, and (a) prevalence of e-cigarette use among current smokers and (b) prevalence of e-cigarette use during quit attempts.
- The association between the proportion of past year smokers who attempted to quit smoking and prevalence of e-cigarette use among current smokers.
- The associations between the percentage of quit attempts involving e-cigarette use and (a) the proportions of past year quit attempts that involved the use of licensed smoking cessation treatments (any prescription treatment, NRT on prescription, and NRT bought over the counter), and (b) the number of smokers who set a quit date with the English stop smoking services.

A set of covariates were added to the models to take account of potential confounding, including tobacco control policies, mass media expenditure, and smoking prevalence.

Methods

Data sources

Data came from two main sources: the Smoking Toolkit Study and the English national health service (NHS) stop smoking services. The Smoking Toolkit Study involves a series of monthly household, face-to-face, computer assisted surveys of representative samples of the population in England aged 16 years or more.[12] The study has been collecting data since November 2006, and uses a type of random location sampling, which is a hybrid between random probability and simple quota sampling. England is first split into over 170 000 output areas, comprising about 300 households. These areas are then stratified according to ACORN characteristics and geographical region (http://acorn.caci.co.uk) and are randomly allocated to interviewers. Data are collected on approximately 1200 smokers each quarter.

Participants from the Smoking Toolkit Study seem to be representative of the population in England, having similar sociodemographic composition and smoking characteristics to large national surveys based on probability samples, such as the Health Survey for England.[12] The study's website (www.smokinginengland.info) provides further details, including the published protocol.[12]

Statistics on use of the NHS stop smoking service were obtained from the NHS Information Centre.[25] These statistics include the quarterly number of individuals setting a quit date at stop smoking services. Before April 2013, these data were collected at the strategic health authority and primary care trust level, before moving to the regional and local authority level after a change in commissioning arrangements.[26]

Measures

The dataset consisted of quarterly data on the explanatory, outcome, and covariates of interest. Details of the questions used to derive these variables are given below.

Explanatory variables

Quarterly data on e-cigarette use among current smokers and among those who made a quit attempt was obtained from the Smoking Toolkit Study. Participants who reported that they smoked cigarettes (including hand rolled cigarettes) every day or less often were asked to answer the following questions by selecting an option from a list of nicotine products (which included e-cigarette use):

1. Which, if any, of the following are you currently using to help you cut down the amount you smoke?
2. Do you regularly use any of the following in situations when you are not allowed to smoke?
3. Can I check, are you using any of the following either to help you stop smoking, to help you cut down, or for any other reason at all?

Prevalence of use of e-cigarettes in current smokers was obtained for each quarter by counting the number of respondents who endorsed use of e-cigarettes in response to any of the three questions above, divided by the number of cigarette smokers. Data were first collected in 2011; prior to this, prevalence was assumed to be stable at 0.1% of smokers based on previous estimations.[27 28]

E-cigarette use during a recent quit attempt was also ascertained from the Smoking Toolkit Study. In the study, past year smokers who had made a quit attempt in the previous 12 months were asked the following question: "Which, if any, of the following did you try to help you stop smoking during the most recent serious quit attempt?"

Past year smokers answered the question by selecting from a list of cessation aids (including e-cigarette use).

Prevalence of use of e-cigarettes in a quit attempt was calculated for each quarter by dividing the number of respondents who reported having used e-cigarettes by the number of those who reported having made a quit attempt. Data were first collected in 2009; prior to this, prevalence was assumed to be stable at 0.1%.

Outcome variables

Data on outcome variables also came from the Smoking Toolkit Study. Past year smokers were asked three questions:

1. How many serious attempts to stop smoking have you made in the last 12 months? By serious attempt I mean you decided that you would try to make sure you never smoked again. Please include any attempt that you are currently making and please include any successful attempt made within the last year.
2. How long did your most recent serious quit attempt last before you went back to smoking?
3. Which, if any, of the following did you try to help you stop smoking during the most recent serious quit attempt?

The prevalence of quit attempts in each quarter was calculated as the number of respondents who reported having made one or more quit attempts in the past 12 months divided by the number of past year smokers. The success rate in each quarter was calculated as the number of respondents reporting that they were still not smoking divided by the number reporting having made a quit attempt.

For each quarter, we calculated the prevalence of use of (1) NRT over the counter, (2) NRT on prescription, and (3) any treatment on prescription (NRT, bupropion, or varenicline) by dividing the number of respondents reporting use of each aid by the number reporting that they had tried to quit in the past 12 months. In England, over-the-counter treatments, or the self medication market, refer to all products that can be brought in pharmacies and other shops (including supermarkets) without a prescription.

Statistics on the use of the NHS stop smoking service were obtained from the NHS Information Centre.[25] Data were available up to the first quarter of 2015.

Other covariates

In England, tobacco mass media campaigns have been run as part of a national tobacco control programme. Spending was almost completely suspended in 2010 and then reintroduced in 2011 at a much lower level. Previous studies have shown that such cuts were associated with a decreased use of smoking cessation support.[23 29] Thus, advertising expenditure was included as adjustment. Data were obtained from Public Health England.

Several tobacco control policies were adjusted for in the analyses (assuming pulse effects). These adjusted policies included the change in commissioning of stop smoking services from central to local authorities in April 2013,[26] the introduction of a smoking ban in July 2007,[30] and the change in the minimum age of sale of cigarettes from 16 to 18 years in October 2007.[31]

Smoking prevalence, estimated from the Smoking Toolkit Study, was also included as an additional covariate when assessing the impact on the number of smokers setting a quit date at the stop smoking services. This covariate allows adjustment for the fact that any fall in absolute numbers of people using the services could reflect the overall decline over time in smoking prevalence.

Price of cigarettes increased linearly over time with a correlation of 0.99. Therefore, any effect of price on outcome measures could not be distinguished from a linear change over time for which we were already accounting, by differencing the time series (that is, using the difference between successive values of the outcome variables rather than the values themselves).

Analysis

The analysis plan was registered on the Open Science Framework before data analysis (https://osf.io/fbgj2/). We analysed all data in R version 3.2.1, using autoregressive integrated moving average with exogeneous input (ARIMAX) modelling.[32] ARIMAX is an extension of autoregressive integrated moving average analysis, which produces forecasts based on prior values in the time series (autoregressive terms) and the errors made by previous predictions (moving average terms). Such models have been used to explore the effect of tobacco price and mass media campaigns on smoking prevalence.[33]

We followed a standard ARIMAX modelling approach,[32] which is detailed in supplementary appendix 1. The series were first log transformed to stabilise the variance, and first differenced and seasonally differenced if required. First differencing involves calculating the change between one observation and the next, while seasonal differencing involves calculating the change between one year and the next. The autocorrelation and partial autocorrelation functions were then examined to determine the seasonal and non-seasonal moving average and autoregressive terms. To identify the most appropriate transfer function for the continuous explanatory variables, we checked the sample cross correlation function and compared models with varying lags using the Akaike information criterion. Coefficients can be interpreted as estimates of the percentage change in the outcome of interest for every percentage increase in use of e-cigarettes and mass media, and absolute change as a consequence of tobacco control policies (or $100\times(\exp(\text{coefficient}-1))$ in terms of absolute percentage change). STROBE guidelines were followed throughout.[34]

Patient involvement

No patients were involved in setting the research question or the outcome measures, nor were they involved in developing plans for recruitment, design, or implementation of the study. No patients were asked to advise on interpretation or writing up of results. There are no plans to disseminate the results of the research directly to study participants or any specific patient community.

Results

Sample characteristics

Data were collected on 170 490 individuals aged 16 years and over taking part in the Smoking Toolkit Study who reported their smoking status. Of these participants, 41 301 (weighted 23.1% (95% confidence interval 22.9% to 23.3%; unweighted 24.2% (24.0% to 24.4%)) were past year smokers and 37 765 (21.0% (20.8% to 21.2%); 22.2% (22.0% to 22.3%)) were current smokers. During the study, 8 029 012 individuals set a quit date with their stop smoking service.

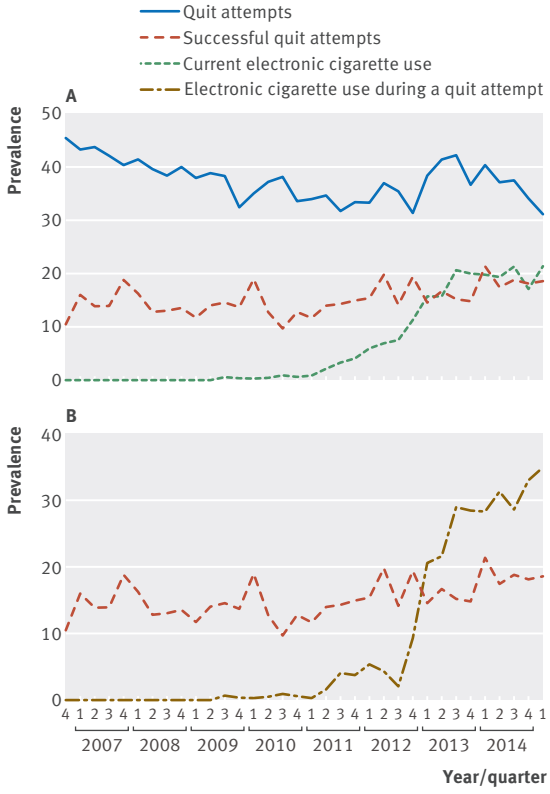

Fig 1 | Quarterly prevalence of (A) self reported quit attempts, success of quit attempts, and current e-cigarette use and (B) success of quit attempts and e-cigarette use during a quit attempt in England. For (A), self reported quit attempt rate is expressed as a proportion of past year smokers; success rate of quit attempts is expressed as a proportion of adults who smoked and tried to stop or who stopped in the past year; and current e-cigarette use is expressed as a proportion of current smokers. For (B), success of quit attempts and e-cigarette use in a recent quit attempt are expressed as a proportion of adults who smoked and tried to stop or who stopped in the past year

Table 1 | Use of smoking cessation treatments during a quit attempt and number of smokers setting a quit date at stop smoking services during the study

	Proportion (%) or No of smokers		
Treatment	Start of study (fourth quarter, 2006)	End of study (first quarter, 2015)	Mean (standard deviation)
Any treatment on prescription (%)	11.0	11.9	16.4 (4.05)
NRT bought over the counter (%)	40.0	20.6	29.0 (5.44)
NRT on prescription (%)	8.5	5.6	8.9 (2.45)
Stop smoking services (No)	119 986	122 954	171 130 (39 795)

NRT=nicotine replacement therapy; prescription treatment=NRT, varenicline, or bupropion.

Figure 1 shows a fall followed by an increase and then a further decline in the proportion of past year smokers reporting a quit attempt. The proportion changed from 45.4% at the start of the study to 31.2% in the last quarter of the study (mean 37.6% (standard deviation 3.8)). There was an overall increase in the success rate of those who reported a quit attempt (from 10.6% in the last quarter of 2006 to 18.6% in the first quarter of 2015; overall mean 15.2% (standard deviation 2.8)). Over the same period, current use of e-cigarettes among smokers increased from negligible use in the last quarter of 2006 to 21.3% at the end of the study (mean 6.4% (standard deviation 8.2)), and e-cigarette use in a quit attempt also rose from negligible use in the last quarter of 2006 to 35.0% in the first quarter of 2015 (8.6% (12.5)).

Table 1 shows the proportion of smokers using various treatments during their most recent quit attempt, and the number of smokers setting a quit date with stop smoking services. Figure 2 shows that use of prescribed treatment and stop smoking services rose up to the fourth quarter of 2011, after which there was a decline. In contrast, use of NRT obtained over the counter and on prescription declined steadily. Supplementary figure 1 shows the changes in smoking prevalence and mass media expenditure over time, and the time points for the introduction of the relevant tobacco control policies.

Association between e-cigarette use among current smokers and during a quit attempt among those who made a quit attempt and the success of quit attempts

In adjusted analyses, e-cigarette use by smokers was positively associated with the success of attempts to stop, such that for every 1% increase in e-cigarette use, the success of quit attempts increased by 0.098%. E-cigarette use in quit attempts was also positively associated with quit success, with every 1% rise in use associated with a 0.058% increase in the success of attempts. In addition, there was evidence of a rise in successful quitting following the increase in the age of sale of cigarettes, and a positive association between mass media spending and quit success (table 2).

Association between use of e-cigarettes among current smokers and quit attempts

In adjusted and unadjusted analyses, the data were inconclusive as to whether an association was present between current use of e-cigarettes by smokers and attempts to quit smoking (table 3).

Association between use of e-cigarettes during a quit attempt among those who made a quit attempt on use of prescription treatment, prescription NRT, over-the-counter NRT, and specialist services

After adjustment, the findings were inconclusive as to whether an association was present between e-cigarette use during a quit attempt and the use of stop smoking services, NRT over the counter, and prescription treatment. However, a significant association was found with use of NRT on prescription: for every 1% increase in e-cigarette use in a quit attempt, the use of

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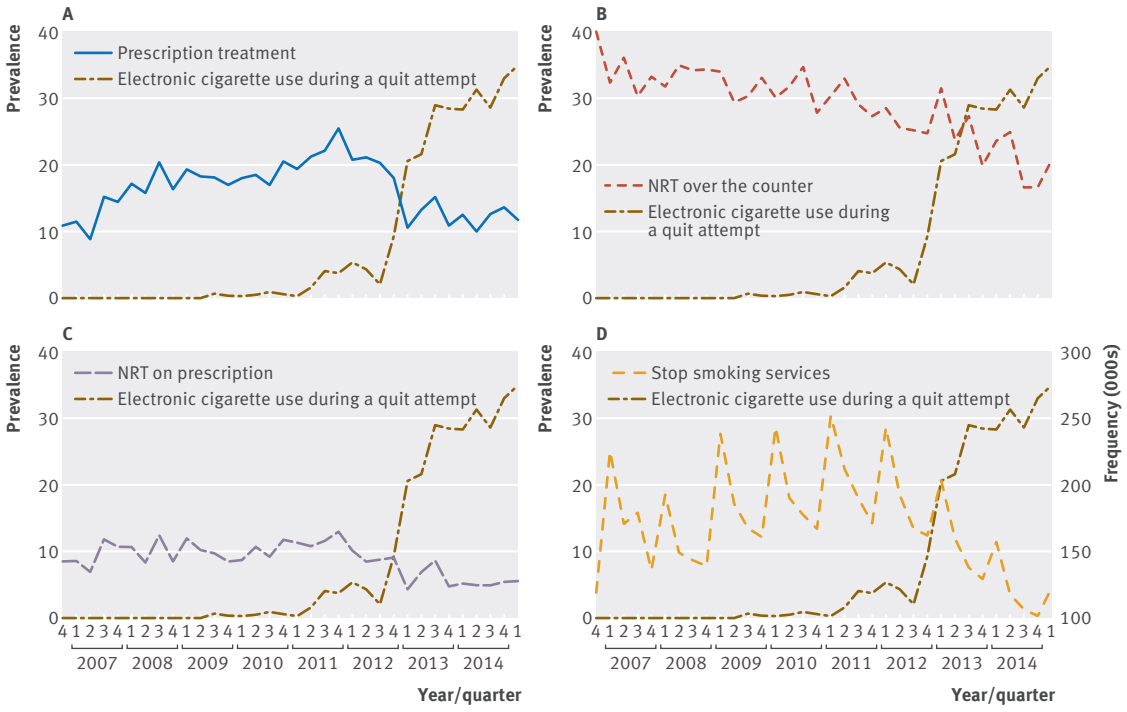

Fig 2 | Quarterly prevalence of e-cigarette use during a quit attempt and (A) prescription treatment during a quit attempt, (B) NRT obtained over the counter during a quit attempt, (C) NRT on prescription during a quit attempt, and (D) quarterly number of smokers setting a quit attempt with stop smoking services in England. With the exception of the service use data, all usage data in the figure are expressed as a proportion of adults who smoked and tried to stop or who stopped in the past year

prescription treatment fell by 0.098%. There was evidence that expenditure on mass media was positively associated with use of stop smoking services (table 4).

Power

Power analyses (based on McLeod and Vingili[35]) indicated that the study had 80% power to detect the following changes, as a consequence of a 1% change in e-cigarette use[36]:

- 0.07% change in quit attempts predicted from current e-cigarette use
- 0.034% and 0.113% change in the success of quit attempts when predicted from use during a quit attempt and from current e-cigarette use, respectively
- 0.113% change in use of stop smoking services
- 0.137% change in use of any prescription treatment
- 0.145% change in use of NRT on prescription
- 0.116% change in the use of NRT obtained over the counter.

Discussion

Principal findings

The increase in e-cigarette use in England has been positively associated with the success rates of quit attempts after adjustment for a range of confounding variables. No clear association has emerged between e-cigarette use and prevalence of quit attempts or use of licensed NRT bought over the counter, prescription treatment, or behavioural support. However, use of e-cigarettes in quit attempts has been negatively associated with use of NRT on prescription.

Strengths and limitations of study

To our knowledge, this is the first empirical study to estimate the population impact of e-cigarettes on attempts to quit smoking and their success, the use of smoking cessation pharmacotherapy, and the use of stop smoking services, using a time series approach. Strengths of the study are the use of a large representative sample of the English population, in addition to service use data.

The study had several limitations. Firstly, estimates of the impact of some tobacco control policies were implausibly large and confidence intervals wide, particularly for the increase in age of sale of cigarettes from 16 to 18 years, suggesting caution when drawing conclusions about these variables. Event type explanatory variables with short time periods before their occurrence in ARIMA type models often give inaccurate estimates and wide standard errors.[37] Thus, the short lead in period could have created a spurious association in the present study,[35] although the increase in age of sale in England has been previously associated with a decline in smoking prevalence in younger age groups.[31] Future studies should consider variations in the impact of tobacco control policies, such as more prolonged pulse effects, delayed effects, and sustained effects.[32]

Secondly, the impact of the move from central to local authority control may be better explained by the inclusion of a variable reflecting expenditure by stop smoking services. However, such data were not available. Thirdly, the Smoking Toolkit Study required participants to recall use of aids during the previous 12 months, which could have introduced bias. Fourthly, the findings might not gener-

Table 2 | Estimated percentage point changes in the proportion of quitters who met criteria for quit success during the study (last quarter of 2006 to first quarter of 2015), based on autoregressive integrated moving average with exogeneous input (ARIMAX) models

	Analysis of e-cigarette use during a quit attempt*		Analysis of current e-cigarette use†	
	Unadjusted	Fully adjusted	Unadjusted	Fully adjusted
Percentage change per 1% change in the exposure (95% CI), P value				
Use of e-cigarettes in a quit attempt	0.042 (0.018 to 0.065), <0.001	0.058 (0.038 to 0.078), <0.001	NA	NA
Use of e-cigarettes by current smokers	NA	NA	0.076 (−0.002 to 0.155), 0.06	0.098 (0.064 to 0.132), <0.001
Mass media expenditure	—	0.059 (0.020 to 0.097), 0.003	—	0.063 (0.025 to 0.101), 0.001
Total change due to the exposure (95% CI), P value				
Smoking ban (temporary impact in third quarter of 2007)	—	0.022 (−0.224 to 0.268), 0.86	—	0.005 (−0.237 to 0.246), 0.97
Increase in age of sale (temporary impact in fourth quarter of 2007)	—	0.328 (0.081 to 0.574), 0.009	—	0.345 (0.105 to 0.585), 0.005
Move to local authority control (temporary impact in second quarter of 2013)	—	−0.047 (−0.293 to 0.200), 0.71	—	−0.029 (−0.265 to 0.207), 0.81
Best fitting model				
ARIMAX	$(0,1,1)(0,0,0)^4$	$(0,1,1)(0,0,0)^4$	$(0,1,1)(0,0,0)^4$	$(0,1,1)(0,0,0)^4$
Non-seasonal (P value)				
Autoregressive term‡	NA	NA	NA	NA
Moving average term‡	<0.001	<0.001	<0.001	<0.001
Seasonal (P value)				
Autoregressive term‡	NA	NA	NA	NA
Moving average term‡	NA	NA	NA	NA
R^2	0.26	0.55	0.23	0.57

NA=not appropriate.
*See supplementary appendix 2 for details (table 2 note a).
†See supplementary appendix 2 for details (table 2 note b).
‡Autoregressive (AR) and moving average (MA) terms are types of autocorrelation. AR(1) means that the value of a series at one point in time is the sum of a fraction of the value of the series at the immediately preceding point in time and an error component; MA(1) means that the value of a series at one point in time is a function of a fraction of the error component of the series at the immediately preceding point in time and an error component at the current point in time.

Table 3 | Estimated percentage point changes in the proportion of past year smokers who attempted to quit during the study (last quarter of 2006 to first quarter of 2015), based on autoregressive integrated moving average with exogeneous input (ARIMAX) models

	Unadjusted*	Fully adjusted*
Percentage change per 1% change in the exposure (95% CI), P value		
Use of e-cigarettes	0.023 (−0.037 to 0.083), 0.46	0.025 (−0.035 to 0.085), 0.41
Mass media expenditure	—	−0.008 (−0.039 to 0.022), 0.59
Total change due to the exposure (95% CI), P value		
Smoking ban (temporary impact in third quarter of 2007)	—	−0.017 (−0.138 to 0.103), 0.78
Increase in age of sale (temporary impact in fourth quarter of 2007)	—	−0.037 (−0.159 to 0.083), 0.54
Move to local authority (temporary impact in second quarter of 2013)	—	0.031 (−0.039 to 0.022), 0.57
Best fitting model		
ARIMAX	$(0,1,0)(0,0,0)^4$	$(0,1,0)(0,0,0)^4$
Non-seasonal (P value)		
Autoregressive term†	NA	NA
Moving average term†	NA	NA
Seasonal (P value)		
Autoregressive term†	NA	NA
Moving average term†	NA	NA
R^2	0.52	0.53

NA=not appropriate.
*See supplementary appendix 2 for details (table 3 note a).
†Autoregressive (AR) and moving average (MA) terms are types of autocorrelation. AR(1) means that the value of a series at one point in time is the sum of a fraction of the value of the series at the immediately preceding point in time and an error component; MA(1) means that the value of a series at one point in time is a function of a fraction of the error component of the series at the immediately preceding point in time and an error component at the current point in time.

Table 4 | Estimated percentage point changes in the proportion of smokers using stop smoking services and pharmacotherapy during a quit attempt (from last quarter of 2006 to first quarter of 2015), based on autoregressive integrated moving average with exogeneous input (ARIMAX) models

	Stop smoking services		Prescription treatment		NRT over the counter		NRT on prescription	
	Adjusted for smoking prevalence*	Fully adjusted*	Unadjusted†	Fully adjusted†	Unadjusted‡	Fully adjusted‡	Unadjusted§	Fully adjusted§
Percentage change per 1% change in the exposure (95% CI), P value								
Use of e-cigarettes in a quit attempt	−0.012 (−0.091 to 0.067), 0.77	−0.013 (−0.102 to 0.077), 0.78	−0.069 (−0.161 to 0.022), 0.14	−0.070 (−0.152 to 0.013), 0.10	−0.016 (−0.096 to 0.065), 0.70	−0.006 (−0.088 to 0.077), 0.89	−0.086 (−0.187 to 0.015), 0.10	−0.098 (−0.189 to −0.007), 0.04
Mass media expenditure	—	0.013 (0.005 to 0.021), 0.001	—	−0.013 (−0.015 to 0.041), 0.37	—	−0.008 (−0.053 to 0.037), 0.74	—	−0.051 (−0.107 to 0.006), 0.08
Total change due to the exposure (95% CI), P value								
Smoking ban (temporary impact in third quarter of 2007)	—	−0.019 (−0.294 to 0.257), 0.89	—	0.173 (−0.097 to 0.442), 0.21	—	−0.128 (−0.344 to 0.087), 0.24	—	−0.128 (−0.344 to 0.087), 0.24
Increase in age of sale (temporary impact in fourth quarter of 2007)	—	0.011 (−0.219 to 0.238), 0.92	—	0.077 (−0.190 to 0.343), 0.57	—	−0.027 (−0.242 to 0.189), 0.81	—	−0.027 (−0.242 to 0.189), 0.81
Move to local authority (temporary impact in second quarter of 2013)	—	0.034 (−0.162 to 0.230), 0.73	—	0.056 (−0.225 to 0.337), 0.70	—	−0.075 (−0.303 to 0.152), 0.52	—	−0.075 (−0.303 to 0.152), 0.52
Best fitting model								
ARIMAX	$(1,1,0)(0,0,1)^4$	$(1,1,0)(0,0,1)^4$	$(1,1,0)(0,0,0)^4$	$(1,1,0)(0,0,1)^4$	$(0,1,1)(0,0,0)^4$	$(0,1,1)(0,0,0)^4$	$(0,1,1)(0,0,0)^4$	$(0,1,1)(0,0,0)^4$
Non-seasonal (P value)								
Autoregressive term¶	0.01	0.001	0.002	0.008	NA	NA	NA	NA
Moving average term¶	NA	NA	NA	NA	<0.001	0.002	<0.001	<0.001
Seasonal (P value)								
Autoregressive term¶	NA	NA	NA	NA	NA	NA	NA	NA
Moving average term¶	0.001	<0.001	NA	0.92	NA	NA	NA	NA
R^2	0.46	0.67	0.64	0.72	0.69	0.71	0.52	0.68

NA=not appropriate.
*See supplementary appendix 2 for details (table 4 note a).
†See supplementary appendix 2 for details (table 4 note b).
‡See supplementary appendix 2 for details (table 4 note c).
§See supplementary appendix 2 for details (table 4 note d).
¶Autoregressive (AR) and moving average (MA) terms are types of autocorrelation. AR(1) means that the value of a series at one point in time is the sum of a fraction of the value of the series at the immediately preceding point in time and an error component; MA(1) means that the value of a series at one point in time is a function of a fraction of the error component of the series at the immediately preceding point in time and an error component at the current point in time.

alise to other countries. England has a strong tobacco control climate and generally high motivation to quit among smokers, and relatively liberal regulation of e-cigarettes. In countries with weaker tobacco control, or stricter regulation of e-cigarettes, different effects may be observed. Fifthly, although we are unaware of any other major population level interventions or other events during the study period, we cannot rule out residual confounding. Sixthly, caution should be taken when interpreting null effects, and readers should not assume that they represent no association.[38] Instead, we can only conclude that in the presence of a P value greater than 0.05, the data are inconclusive as to whether an association exists[39]; although this study was powered to detect relatively small associations.

Finally, for a full assessment of the impact of e-cigarettes on public health, future studies should assess the impact on use among never smokers. Although previous studies report a rise in experimentation by never smokers, regular use is rare at below 1%.[40-43] Consideration is also needed as to what might have contributed to the decline in rates of attempts to quit smoking in recent years. Studies suggest a possible role of reduced spending on mass media campaigns[23]; that smokers have become inured to smoking cessation messages[44]; and the financial crisis and austerity measures within Europe.[45] We did not find a clear impact of any of our measures on quit attempts over the period studied.

Comparison with other studies

The findings of the present study conflict with the hypothesis that an increase in population use of e-cigarettes undermines quitting in general, but it may have reduced the use of NRT on prescription. If the link between change in e-cigarette use and smoking cessation rate is causal, then every 10 percentage point increase in e-cigarette use in quit attempts would result in a 0.58 percentage point change in successful quit attempts, other things being equal. With quit attempts at 32.5% of eight million smokers (2.6 million) in 2015, and prevalence of e-cigarette use in quit attempts at 36% in that year, this equates to 54 288 additional short to medium term quitters in 2015 compared with no use of e-cigarettes in quit attempts.[21] We would expect up to two thirds of these individuals to relapse at some point in the future, so we would estimate that e-cigarettes may have contributed about 18 000 additional long term ex-smokers in 2015. This figure is similar to that estimated indirectly using the estimated effect size of e-cigarettes and the numbers using them.[21]

Although these numbers are relatively small, they are broadly similar to previous estimates,[21] and are clinically significant because of the huge health gains from stopping smoking. A 40 year old smoker who quits permanently can expect to gain nine life years compared with a continuing smoker.[46-48] This number of additional quitters is unlikely to produce a detectable effect on smoking prevalence in the short term, but might be picked up over a period of several years.

The finding of an impact on prevalence of use of NRT obtained on prescription but not over the counter is difficult to explain. One possibility is that health professionals are discussing the options with patients who are then choosing to use e-cigarettes, perhaps having already tried NRT.[49-51] This issue requires further research. These findings suggest that e-cigarettes have possibly not been responsible for the large decline in NRT obtained over the counter market.[10] It is possible that the trend reflects longer term disillusionment with licensed nicotine products, which warrants further investigation.

Conclusion and policy implications

The increased prevalence of e-cigarettes in England does not appear to have been associated with a detectable change in attempts to stop smoking. However, the increase in e-cigarette use has been associated with an increase in success of quit attempts. Growth in the use of e-cigarettes for quitting has also been associated with a decline in use of NRT obtained on prescription, but has not clearly been associated with the use of other quitting support.

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Data sharing: For access to the Smoking Toolkit Study, please contact RW (robertwest100@googlemail.com). The R code for this paper is available at https://osf.io/yqaxm/; this code is licensed under a Creative Commons Attribution 4.0 International License, and this research paper should be acknowledged when used.

The lead author (the manuscript's guarantor) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have

been omitted; and that any discrepancies from the study as planned have been registered and explained.

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Supplementary appendix: Additional material