ADDICTION
SSA SOCIETY FOR THE STUDY OF ADDICTION
RESEARCH REPORT
doi:10.1111/add.14119

E-cigarette price sensitivity among middle- and high-school students: evidence from monitoring the future

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ABSTRACT

Aims We estimated associations between e-cigarette prices (both disposable and refill) and e-cigarette use among middle and high-school students in the United States. We also estimated associations between cigarette prices and e-cigarette use. **Design** We used regression models to estimate the associations between e-cigarette and cigarette prices and e-cigarette use. In our regression models, we exploited changes in e-cigarette and cigarette prices across four periods of time and across 50 markets. We report the associations as price elasticities. In our primary model, we controlled for socio-demographic characteristics, cigarette prices, tobacco control policies, market fixed effects and year-quarter fixed effects. **Setting** United States of America. **Participants** A total of 24 370 middle- and high-school students participating in the Monitoring the Future Survey in years 2014 and 2015. **Measurements** Self-reported e-cigarette use over the last 30 days. Average quarterly cigarette prices, e-cigarette disposable prices and e-cigarette refill prices were constructed from Nielsen retail data (inclusive of excise taxes) for 50 US markets. **Findings** In a model with market fixed effects, we estimated that a 10% increase in e-cigarette disposable prices is associated with a reduction in the number of days vaping among e-cigarette users by approximately 9.7% [95% confidence interval (CI) = −17.7 to 1.8%; $P = 0.02$] and is associated with a reduction in the number of days vaping by the full sample by approximately 17.9% (95% CI = −31.5 to −4.2%; $P = 0.01$). Refill e-cigarette prices were not statistically significant predictors of vaping. Cigarette prices were not associated significantly with e-cigarette use regardless of the e-cigarette price used. However, in a model without market fixed effects, cigarette prices were a statistically significant positive predictor of total e-cigarette use. **Conclusions** Higher e-cigarette disposable prices appear to be associated with reduced e-cigarette use among adolescents in the US.

Keywords E-cigarettes, electronic nicotine delivery systems, price sensitivity, tobacco control, tobacco use, youth.

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Submitted 3 April 2017; initial review completed 17 July 2017; final version accepted 21 November 2017

INTRODUCTION

In 2014 in the United States, electronic nicotine delivery systems (ENDS, also known as e-cigarettes) overtook cigarette use among youth as the most commonly used tobacco product [1,2]. The high rate of e-cigarette use among youth has generated debate among researchers, policymakers, the media and the general public. Some argue that e-cigarettes harm adolescent health by causing nicotine addiction, serving as a 'gateway' to more dangerous tobacco products and harming adolescent cognitive development [3]. Other studies, however, suggest that current scientific evidence is insufficient to support a gateway theory [4], and suggest that e-cigarette restrictions may even increase teenage cigarette use [5,6].

To date, state governments have responded to high e-cigarette use among youth by enacting minimum legal sale age (MLSA) laws, as well as imposing excise taxes on e-cigarettes. As of the 2nd quarter of 2017, seven states and Washington, DC, along with a number of localities, taxed e-cigarettes (or liquid nicotine) [7]. In addition, more than a dozen states have introduced bills to tax e-cigarettes [8].

Despite the accelerated pace in adopting e-cigarette taxes at state and local levels, the empirical evidence on the effectiveness of these tax/price policies on reducing e-cigarette use among young people is limited. Recent

studies have shown that the pattern of e-cigarette use among youth may be different from that among adults in that much of youth use reflects experimentation, rather than heavy use [9]. For example, imposing an e-cigarette tax may have smaller impacts among teens who are experimenting and may have larger impacts among teens who are heavy e-cigarette users. Additionally, price elasticities may be smaller (in absolute magnitude) for youth if they are sharing devices regularly. According to the 2015 National Youth Tobacco Survey (NYTS), 11.2% of students reported currently using e-cigarettes and 90% of them received e-cigarettes from a friend at least once during the last 30 days, which suggests substantial rates of sharing [10]. Finally, price elasticities may be smaller (in absolute magnitude) if teenagers are using e-cigarettes without nicotine [11,12], which would reduce future consumption due to addiction.

Several studies have explored e-cigarette price sensitivity among a broader population than young people. One study used a discrete choice experiment to estimate an e-cigarette price elasticity among current adult smokers of −1.8, suggesting that a 10% rise in disposable e-cigarette prices reduces e-cigarette demand by 18% [13]. Two studies have evaluated the relationship between market-level prices and market-level sales, finding e-cigarette own-price elasticities of demand of −1.2 for disposable e-cigarettes and −1.9 for re-usable e-cigarettes in the United States (during the period 2009–12) [14] and −0.8 for disposable e-cigarettes for six European Union countries (during the period 2011–14). The latter study also documented evidence that cigarettes are substitute goods for e-cigarettes [15], a conclusion also reached from a study using experimental data on smokers in New Zealand [16]. One discrete choice experiment has found evidence that disposable e-cigarettes and rechargeable e-cigarettes are substitute products [17].

As discussed above, previous studies have estimated e-cigarette price sensitivity separately for disposables and refillables. In the United States, one meta-analysis estimates that only 15% of youth use disposable e-cigarettes [18]. The 2015 NYTS asked students about life-time use of different e-cigarette products, and found that 4.0% of respondents had only used e-cigarette disposables, 13.3% had only used e-cigarette rechargeable/refillable tank systems and 8.2% had used both products [10].

In addition, substantial scholarly effort has been devoted to estimating cigarette price sensitivity among youth. One review of 55 studies of price elasticities for young people in high-income countries estimated a price elasticity range of between −0.5 and −1.2 [19]. Recent estimates from the United States Community Services Task Force have found a young person price elasticity of −0.74 (using 13 studies), a young person prevalence of tobacco use price elasticity of −0.36 (using 22 studies) and a median young person initiation of tobacco use price elasticity of −0.43 (using seven studies) [20]. One review of 27 studies reached a different conclusion on the narrow outcome of youth smoking initiation, finding no strong evidence that tobacco prices or taxes affects smoking initiation [21].

The empirical evidence on the effectiveness of e-cigarette taxing and pricing policies on youth e-cigarette use (e.g. vaping) is scarce. We filled this critical gap by estimating the relationship between e-cigarette retail prices and use of e-cigarettes among American middle- and high-school students in 2014 and 2015 using the Monitoring the Future (MTF) data. Our study will be among the first to examine youth e-cigarette price elasticities, and will provide evidence on the effectiveness of e-cigarette taxing and pricing policies in deterring and reducing youth vaping. In particular, we estimateed associations between the prices of disposable e-cigarettes, refill e-cigarettes and traditional cigarettes on e-cigarette use among middle- and high-school students in the United States.

METHODS

Design

We estimated regression models to calculate the associations between e-cigarettes prices (either e-cigarette disposable or refill prices) and cigarette prices on e-cigarette use. Due to data limitations in terms of when e-cigarette use questions were added to MTF and availability of e-cigarette prices from Nielsen, we performed our analysis using data from years 2014 and 2015.

Sample

We used e-cigarette information from the 2014 and 2015 MTF surveys, a nationally representative survey of the US middle- and high-school students conducted by the University of Michigan between February and June of each year. University of Michigan staff members administer the questionnaires to 8th-, 10th- and 12th-grade students, usually in the student classroom during a regular class period. A multi-stage random sampling procedure was used to secure the nation-wide sample of students in each year, with geographic areas being selected in stage 1, selection with probability proportionate to size of one or more schools in each area in stage 2 and classrooms selected from the schools in stage 3 [22]. During initial school recruitment, those schools refusing participation were replaced with similar schools in terms of geographic location, size and type of school (e.g. public, private/Catholic, private/non-Catholic) [23].

MTF samples 72 first-stage geographic units per year and approximately six schools were surveyed per geographical unit. MTF interviews only one grade per school.

Typically, MTF surveys the entire grade, although a random sample is taken if the grade has more than 350 students.

A total of 377 schools were surveyed in 2014 and 382 schools were surveyed in 2015. Schools participate in the survey for 2 years, and approximately half the schools participated for both years during the 2014–15 time-period. In 2014, the 8th-grade student response rate (conditional on school participation) was 90%, the 10th-grade student response rate was 88% and the 12th-grade student response rate was 82%. In 2015, the 8th-grade student response rate was 89%, the 10th-grade student response rate was 87% and the 12th-grade student response rate was 83% [24].

The number of observations that we have available for each quarter/year are 3394 (2014, Q1); 8459 (2014, Q2), 3571 (2015, Q1) and 8946 (2015, Q2). The higher numbers in the second quarter of each year are due to greater data collection during that quarter.

Outcomes

Starting in 2014, an e-cigarette question asking: 'During the LAST 30 DAYS, on how many days (if any) have you used electronic cigarettes (e-cigarettes)?' was asked to a random sample of students participating in the MTF survey. In 2014, the question was asked on two of four survey forms that were randomized among 8th- and 10th-grade students completing the survey, and four of six forms for 12th-graders. The same question was asked on three of four forms for 8th- and 10th-graders in 2015. The survey forms were assigned randomly within MTF schools; in this way, e-cigarette responses were collected from each grade surveyed by MTF. Students had the option to answer the question with: (1) none, (2) 1–2 days, (3) 3–5 days, (4) 6–9 days, (5) 10–19 days and 6() 20–30 days.

Price measures

E-cigarette and cigarette price data came from the store scanner data compiled by the Nielsen Company, which includes food, drug and mass merchandise (FDM) stores in 52 US markets in a given year. A Nielsen market consists of groups of counties centered on a major city. In many cases, counties in the same Nielsen market belong to different states, as a Nielsen market can cross state borders and cover areas in two or multiple states. Nielsen participating retailers include mass stores (such as K-Mart and Target), drug stores (such as CVS, Walgreens and RiteAid) and grocery stores (such as Kroger, Food Lion, Publix, Safeway, Albertsons and Winn Dixie). The population residing in those 52 Nielsen markets represents approximately 80% of the total US population.

We used the Nielsen store scanner data to construct quarterly market-level prices for all e-cigarettes and cigarettes sold at participating retailers. Two different types of e-cigarette prices were constructed, e-cigarette disposable prices and e-cigarette refill prices. We first identified sales of e-cigarette disposables and refills. We then determined the total payments by consumers for each type of e-cigarette (inclusive of excise taxes) and total sales volume of each type of e-cigarette in a given market/quarter. Finally, we divided total revenue and total sales to obtain market-quarter prices for e-cigarette disposables and refills. We then assigned these market-quarter prices to MTF respondents depending on the year and quarter in which the students were interviewed and the location of their school.

We did not calculate prices for reusable e-cigarette devices themselves, because they are usually sold in kits, which contain different numbers of batteries and e-liquid refill cartridges, and their prices cannot be standardized easily.

Cigarette prices (per pack) were also constructed by dividing total dollar sales for cigarettes by total number of packs sold in a given market/quarter.

In Fig. 1, we show how Nielsen prices for cigarettes and e-cigarettes changed over time, comparing prices in the 1st quarter 2014 with prices at the same time in 2015. E-cigarette prices varied considerably across markets between 2014 and 2015, potentially reflecting rising demand for e-cigarettes and industry activity as traditional tobacco companies entered into the market, to the detriment of e-cigarette-only companies [3]. Conversely, cigarette prices varied relatively little.

The market-level prices that we constructed were not necessarily the prices actually paid by respondents. Respondents may pay different prices due to, among other things, price distortions caused by inability to legally purchase e-cigarette in stores and brand selection. Respondents may have also purchased the e-cigarettes that they now use at an earlier period of time than recorded by our data (e.g. stockpiling).

Covariates

We also controlled for a variety of individual-level demographic data and county-level tobacco policy data. These variables may have a direct effect on e-cigarette use and could also proxy anti-tobacco sentiment that may affect e-cigarette use (e.g. through social norms) and prices (e.g. through enacting taxes, for example).

The individual-level MTF data that we controlled for included indicators for each of the following age categories (≤ 13, 14, 15, 16, 17, 18, ≥ 19, missing), grade categories (8, 10, 12), gender categories (female, male, missing), race/ethnicity categories (white non-Hispanic, black non-

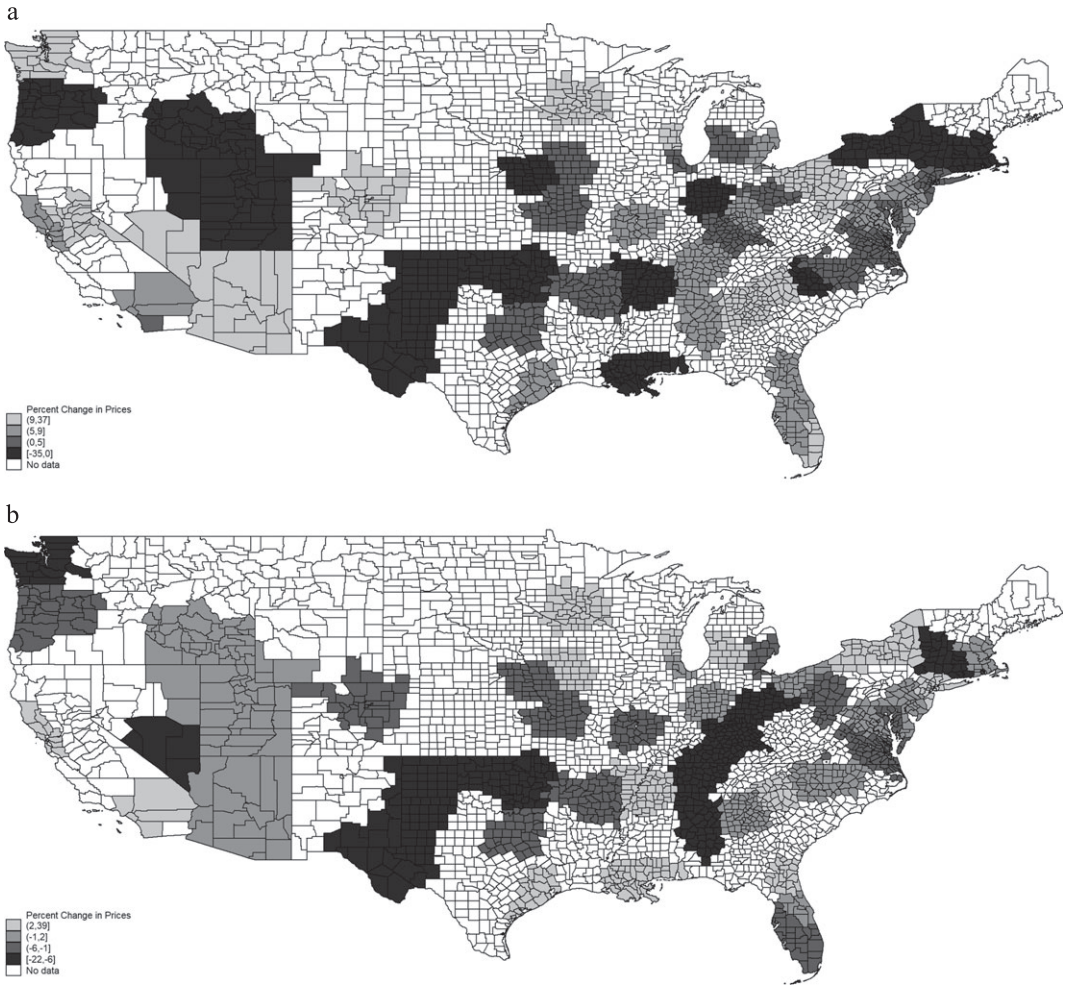

Figure 1 Maps showing percentage change in Nielsen tobacco prices from 2014 to 2015. (a) E-cigarette disposable price percentage point change. (b) E-cigarette refill price percentage point change. The Sacramento market is excluded from this map due to incomplete price information

Hispanic, Hispanic, other race and multi-racial and missing), living arrangement categories (both parents, alone, father only, mother only, other/missing), mother and father's education categories (some high school, high school, some college, college, graduate student, don't know/missing) and employment status categories (no, yes, missing). We also controlled for weekly money from job, other sources or allowances (single continuous variable). Approximately 3.4% of income values were missing, and we imputed linearly for these missing incomes using all demographics (described above), market fixed effects (e.g. a fixed parameter for each market) and year-quarter fixed effects. Estimates of price sensitivity were not affected meaningfully by controlling or not for grade (which is collinear with age).

We also matched on other important policy variables. We obtained dates of the implementation of e-cigarette minimum legal sale age (MLSA) laws at the state-level from the CDC STATE System [7] and county-level MLSA laws from a white paper [25]. We used these data to control or not for the presence of a county-level e-cigarette MLSA law (1 = present, 0 = not present). We also interacted the e-cigarette MLSA law with an 'underage' variable to estimate the effect of an e-cigarette MLSA for only those younger than the legal age. The 'underage' variable is generally 18 years, except in Alabama, Alaska, New Jersey, Utah, Suffolk County and New York City, in which it is 19 or 21 years. Both the interaction of MLSA with underage and both constitutive elements of the interaction were controlled for in all regressions.

We also controlled for the percentage of the county population covered by county- or city-level complete bans (or only minor exemptions) on smoking in bars, restaurants and private work-places, using data obtained from the Americans for Nonsmokers' Rights Foundation.

In our primary specification we controlled for market fixed effects (0/1 variable for each of the 50 markets) and year-quarter fixed effects (0/1 variable for the 1st quarter of 2014, the 2nd quarter of 2014, the 1st quarter of 2015 and the 2nd quarter of 2015). Market fixed effects

removes all time-invariant, market-specific effects, and year-quarter fixed effects removes all time-varying effects across the nation as a whole.

Data analysis

We estimateed a traditional demand equation by regressing e-cigarette use onto e-cigarette prices. We evaluated three separate measures of e-cigarette use as dependent variables: (1) current e-cigarette use, defined as any e-cigarette use over the past 30 days (no = 0; yes = 1), (2) the number of days using e-cigarettes over the past 30 days among current e-cigarette users and (3) the number of e-cigarette days during the past 30 days among all respondents (setting non-e-cigarette user days to 0). For the e-cigarette days-dependent variables, the mid-points of the categories were used (e.g. 7.5 was used for individuals reporting 6–9 days of e-cigarette use during the past 30 days).

Our primary independent variable of interest was the quarterly, market-level e-cigarette price. In a regression framework, the coefficient on this variable shows the relationship that e-cigarette prices have on e-cigarette demand. We also controlled for cigarette prices in the same regression analysis. The estimates for cigarette prices in this equation provided evidence on whether cigarettes were economic substitutes or complements for e-cigarette use by adolescents and young adults. If cigarette prices were found to be associated positively with e-cigarette use, this suggested that the products were economic substitutes; if associated negatively, then the products were economic complements.

In our primary specification we controlled for market fixed effects (0/1 variable for each of the 50 markets) and year-quarter fixed effects (0/1 variable for the 1st quarter of 2014, the 2nd quarter of 2014, the 1st quarter of 2015 and the 2nd quarter of 2015). In an alternative specification, we did not control for market fixed effects to explore how e-cigarette and cigarette price sensitivity was influenced by using both within- and across-market variation in prices. In this specification, we continued to control for the state- and county-level tobacco policy variables mentioned previously.

We estimated any e-cigarette use over the past 30 days (1 = any use, 0 = no use) using a logit model (extensive margin). We estimated conditional demand (i.e. number of vaping days using the sample of only people that vape) and total demand (i.e. number of vaping days using the full sample, setting to 0 people who do not vape) using a generalized linear model (GLM) model with a log-link and a Poisson distribution, as chosen by modified Park tests [26]. The modified Park test is a diagnostic test that examines the residual structure, including how it is impacted by a large number of zeros in the dependent variable in the case of the total margin model, and suggests a distribution that models the data most efficiently. For both the conditional and total margin, the modified Park test determined that a Poisson distribution was the most efficient distribution to use. The modified Park test is used frequently for smoking intensity measures [27,28].

Our conditional model results will be influenced by changes to the sample of e-cigarette users shown on the extensive margin. For example, if e-cigarette use declines in response to e-cigarette price increases, the conditional model will be influenced by whether the remaining users are, on average, heavier users of e-cigarettes than prior to the decline. The total use margin removes the influence of this changed sample from affecting the results; therefore, both models have useful interpretation.

We present estimates from these logit or GLM models as price elasticities. Price elasticities show the percentage change in quantity demanded for a 10% increase in the price. Standard errors were clustered at the market level in our primary analysis; however, we show that standard errors are similar if we cluster alternatively at the school level.

RESULTS

Descriptive statistics for our data are provided in Table 1. Approximately 25% of the sample was in grade 8, 29% of the sample was in grade 10 and 46% of the sample was in grade 12. The higher rate of grade 12 students reflects the e-cigarette question being part of four of six questionnaire forms used for grade 12 compared to two of four used for grades 8 and 10. White non-Hispanics made up approximately 50% of the respondents; 36% of the students had jobs and the average student received $46 in weekly income (from jobs, allowance and/or other sources). Due in part to Nielsen prices being available for only a group of counties centered on a large city, 82% of the sample lived in urban areas; 7.5% of the students had smoked cigarettes and 13.9% had vaped during the past 30 days. The average student who vaped did so on 7.5 days during the past 30 days. The average price in the sample was $8.35 for a single disposable e-cigarette, $3.07 per cartridge for e-liquid refills and $5.87 for a pack of cigarettes. Sixty-seven per cent of the students lived in a county with a MLSA law in place, and 85% were covered by a comprehensive smoke-free air policy or a smoke-free policy with only minor exemptions. In Table 2, we show the means of our outcome variables for each quarter of our data.

In Table 3, we report e-cigarette price elasticities for vaping participation, conditional vaping demand and total vaping demand. The results in each column were calculated from a separate model that controls for socio-demographic characteristics, tobacco control policies, market fixed effects and year-quarter fixed effects.

Table 1 Descriptive statistics.

	n	*Mean*	*SD*
Demographics			
Age ≤ 13	2381	0.098	–
Age 14	3318	0.136	–
Age 15	3282	0.135	–
Age 16	3631	0.149	–
Age 17	5135	0.211	–
Age 18	5465	0.224	–
Age ≥ 19	531	0.022	–
Age missing	627	0.026	–
Underage	18 594	0.763	–
Grade 8	6154	0.253	–
Grade 10	6963	0.286	–
Grade 12	11 253	0.462	–
Gender, female	12 031	0.494	–
Gender, male	11 327	0.465	–
Gender, missing	1012	0.042	–
Race/ethnicity, white, non-Hispanic	12 112	0.497	–
Race/ethnicity, black, non-Hispanic	2929	0.120	–
Race/ethnicity, Hispanic	4502	0.185	–
Race/ethnicity, other race, multi-racial	3656	0.150	–
Race/ethnicity, missing	1171	0.048	–
Employment, no	14 997	0.615	–
Employment, yes	8654	0.355	–
Employment, missing	719	0.030	–
Residence, urban	20 044	0.822	–
Residence, rural	2858	0.117	–
Residence, missing urban/rural	1468	0.060	–
Weekly money from job, other sources, allowance	24 370	46.143	34.507
Live with both parents	16 878	0.693	–
Live alone	166	0.007	–
Live with father only	1036	0.043	–
Live with mother only	4855	0.199	–
Live with other/missing	1435	0.059	–
Education			
Father's education, some high school	1009	0.041	–
Father's education, high-school graduate	2366	0.097	–
Father's education, some college	5300	0.217	–
Father's education, college graduate	3265	0.134	–
Father's education, graduate school	5403	0.222	–
Father's education, don't know	3541	0.145	–
Father's education, missing	3486	0.143	–
Mother's education, some high school	966	0.040	–
Mother's education, high-school graduate	1837	0.075	–
Mother's education, some college	4409	0.181	–
Mother's education, college graduate	3857	0.158	–
Mother's education, graduate school	6972	0.286	–
Mother's education, don't know	3968	0.163	–
Mother's education, missing	2361	0.097	–
Outcomes			
Any cigarette use over past 30 days	1822	0.075	–
Any e-cigarette use	3383	0.139	–
Vaping days (past 30 days, among current vapers only)	24 370	7.409	8.300
Vaping days (past 30 days, among all)	24 370	1.029	4.015
Time			
2014, quarter 1	3394	0.139	–
2014, quarter 2	8459	0.347	–

(***Continues***)

Table 1. (Continued)

	n	*Mean*	*SD*
2015, quarter 1	3571	0.147	–
2015, quarter 2	8946	0.367	–
Tobacco environment			
E-cigarette disposable prices	24 370	8.348	0.897
E-cigarette refill prices	24 370	3.071	0.224
Cigarette prices	24 370	5.874	1.348
E-cigarette minimum legal sale age	17 206	0.706	–
Cigarette indoor use air laws (complete or some exceptions)	24 370	0.851	0.221

SD = standard deviation; n = 24 370.

Table 2 Tobacco use over time.

	2014, Q1	*2014, Q2*	*2015, Q1*	*2015, Q2*
Any cigarette use over past 30 days	0.084	0.081	0.070	0.067
Any e-cigarette use	0.152	0.149	0.132	0.127
Vaping days (past 30 days, among current vapers only)	7.306	7.015	7.666	7.789
Vaping days (past 30 days, among all)	1.109	1.048	1.011	0.986
Number of markets	33	48	37	45
Observations	3394	8459	3571	8946

n = 24 370.

The first three columns use e-cigarette disposable prices and the second three columns use e-cigarette refill prices.

We estimated that a 10% increase in e-cigarette disposable prices was associated with a reduction in any e-cigarette use by 6.5%, but this was not significant at $P < 0.05$. A 10% increase in e-cigarette disposable prices is associated with a reduction in conditional e-cigarette demand by approximately 9.7% (column 2, $P = 0.02$), and is associated with a reduction in total e-cigarette days among e-cigarette users and non-users combined by approximately 18% (column 3, $P < 0.01$). The corresponding marginal effects for these estimates (unreported) shows that a $1 increase in e-cigarette prices is associated with a reduction in conditional e-cigarette demand by 0.87 days (21.8% of the mean) and reduces total demand by 0.22 days (21.4% of the mean).

In Table 3, refill e-cigarette prices were not statistically significant predictors of e-cigarette use. Cigarette prices, meanwhile, were not associated significantly with e-cigarette use at any margin, regardless of the e-cigarette price used. There is a consistent negative sign on cigarette prices in all six models, but this was estimated imprecisely.

In Table 4, we report e-cigarette price elasticities for a model without market fixed effects, which uses price variation both within- and throughout markets. In this case, the estimated own-price elasticity of demand for disposable e-cigarettes was attenuated from the case with market fixed effects controlled for, but remained negative. The total demand price elasticity was previously −1.8 and is now −0.2 ($P > 0.05$). The cigarette price elasticity of demand was previously statistically, insignificantly, negative, but is now statistically, significantly, positive. A 10% increase in cigarette prices is associated with an increase in total e-cigarette demand by 3.5%, which suggests that e-cigarettes and cigarettes are economic substitutes. Similar to the model with market fixed effects controlled for, estimates of the effect of refill prices on e-cigarette use remains estimated imprecisely.

We replicated Table 3 results clustering at the level of school (Supporting information, Table S1) and without controlling for cigarette prices (Supporting information, Table S2). We show that the results are substantially similar.

DISCUSSION

Our study used nationally representative data from the 2014 and 2015 MTF survey to assess e-cigarette price impacts on adolescent e-cigarette use. We examined price impacts of e-cigarette disposables and refill cartridges separately, as these products may be used along different stages of the e-cigarette initiation trajectory. We found that prices of disposables had relatively little impact on e-cigarette use participation, but had a large, statistically significant effect on the intensity of use. In our preferred specification with market fixed effects, a 10% increase in prices of disposable

Table 3 E-cigarette own- and cross-price elasticities.

	(1) *E-cigarette use*	*(2)* *Conditional e-cigarette days*	*(3)* *Total E-cigarette days*	*(4)* *E-cigarette use*	*(5)* *Conditional e-cigarette days*	*(6)* *Total E-cigarette days*
E-cigarette disposable prices	−0.649	−0.974*	−1.788*			
	[−1.431, 0.133]	[−1.769, –0.178]	[−3.154, –0.421]			
	(0.104)	(0.016)	(0.01)			
E-cigarette refill prices				−0.426	0.711	0.549
				[−1.759, 0.908]	[−0.514, 1.936]	[−1.621, 2.720]
				(0.532)	(0.255)	(0.62)
Cigarette prices	−0.919	−0.02	−0.258	−1.287	−0.589	−1.232
	[−3.583, 1.744]	[−2.420, 2.379]	[−3.570, 3.055]	[−3.808, 1.235]	[−3.113, 1.935]	[−4.523, 2.058]
	(0.499)	(0.987)	(0.879)	(0.317)	(0.647)	(0.463)
Observations	24 370	3383	24 370	24 370	3383	24 370
Socio-demographics	Yes	Yes	Yes	Yes	Yes	Yes
Tobacco control policies	Yes	Yes	Yes	Yes	Yes	Yes
Market fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year-quarter fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	Logit	GLM, Poisson	GLM, Poisson	Logit	GLM, Poisson	GLM, Poisson

Each column presents price elasticities from a different regression. E-cigarette disposable prices are used in columns 1–3 and e-cigarette refill prices are used in columns 4–6. The price elasticity's 95% confidence interval is shown in square brackets, and the *P*-value is in round brackets. GLM = generalized linear model. *$P < 0.05$.

Table 4 E-cigarette own- and cross-price elasticities, without market fixed effects.

	(1) *E-cigarette use*	*(2)* *Conditional e-cigarette days*	*(3)* *Total E-cigarette days*	*(4)* *E-cigarette use*	*(5)* *Conditional e-cigarette days*	*(6)* *Total E-cigarette days*
E-cigarette disposable prices	−0.113	−0.094	−0.204			
	[−0.635, 0.409]	[−0.519, 0.330]	[−0.957, 0.549]			
	(0.672)	(0.663)	(0.596)			
E-cigarette refill prices				−0.12	0.234	0.19
				[−0.903, 0.663]	[−0.287, 0.755]	[−0.937, 1.318]
				(0.763)	(0.379)	(0.741)
Cigarette prices	0.194	0.168*	0.353*	0.186	0.12	0.287
	[−0.028, 0.415]	[0.015, 0.321]	[0.073, 0.633]	[−0.031, 0.403]	[−0.052, 0.292]	[−0.049, 0.623]
	(0.087)	(0.032)	(0.014)	(0.093)	(0.17)	(0.094)
Observations	24 370	3383	24 370	24 370	3383	24 370
Socio-demographics	Yes	Yes	Yes	Yes	Yes	Yes
Tobacco control policies	Yes	Yes	Yes	Yes	Yes	Yes
Market fixed effects	No	No	No	No	No	No
Year-quarter fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	Logit	GLM, Poisson	GLM, Poisson	Logit	GLM, Poisson	GLM, Poisson

Each column presents price elasticities from a different regression. E-cigarette disposable prices are used in columns 1–3 and e-cigarette refill prices are used in columns 4–6. The price elasticity's 95% confidence interval is in square brackets, and the *P*-value is in round brackets. GLM = generalized linear model. *$P < 0.05$.

e-cigarettes was associated with an approximately 10% reduction in vaping days among current e-cigarette users, or an approximately 19% reduction in vaping days among all adolescents.

The null finding for the effect of e-cigarette prices on e-cigarette participation is not surprising, as the majority of adolescent e-cigarette use within the last 30 days reflects experimentation [29]. Additionally, e-cigarettes are frequently shared, which may make experimentation easier and price sensitivity on the extensive margin harder to measure. For example, the 2015 National Youth Tobacco Survey found that 11.2% of students currently used e-cigarettes and 90% of them had received e-cigarettes from a friend at least once over the last 30 days [10].

Our estimated own-price elasticity for disposable e-cigarettes on vaping days (−1.8%) matched that found in a discrete choice experiment among adult smokers [13], and was slightly higher than those found in two other studies (−0.8 and −1.2) using market-level data [15]. Our price elasticity may be higher than price elasticities estimated based on market-level data because our analysis was focused on adolescents and young adults who, most recent research has concluded, are more responsive than adults to changes in cigarette prices [30]. It may also reflect the importance of using individual level data, as studies based on market-level data are potentially subject to bias towards the null of no effect, as sales may influence prices endogenously.

We did not find significant associations between prices of refill cartridges and any e-cigarette use among adolescents. This is unexpected, because teenagers are less likely to use disposable e-cigarettes [18]. Our lack of precision on estimates with refillable prices may be because these products are easier to share than disposable e-cigarettes, resulting in less ability to measure price sensitivity accurately and precisely for refillable products.

Consistent with existing studies based on e-cigarette market sales data, we did not find a consistent and statistically significant relationship between combustible cigarette prices and e-cigarette use [15]. However, in a model without market fixed effects and using e-cigarette disposable prices, we found that higher cigarette prices increase total e-cigarette use.

Our study is subject to at least three limitations. First, our price data on combustible cigarettes and e-cigarettes came from Nielsen participating retailers, and may not reflect retail prices from internet [31] or local tobacco or vape shops [32]. Secondly, our sample using Nielsen prices under-represented youth living in rural areas. Thirdly, our best measure of e-cigarette intensive margin use was number of days of use, which may have reflected measurement error over using other, more precise, measures of intensive margin use, such as the amount of e-cigarette liquid consumed.

Despite these limitations, our results suggest that higher e-cigarette disposable prices reduce e-cigarette use among adolescents. Consequently, policies that raise retail e-cigarette prices, such as taxes, have the potential to reduce adolescents' e-cigarette initiation and consumption. E-cigarette pricing policies may present an opportunity for states and localities to go above and beyond the Food and drug Administration (FDA)'s 2016 deeming rule to regulate e-cigarettes [33].

Declaration of interests

None.

Acknowledgements

This project was funded by U01CA154248 from the National Cancer Institute (Principle investigator F.C.) and R01DA01411 from the National Institute on Drug Abuse (Principle investigator L.J.).

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Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article.

Table S1 E-cigarette own- and cross-price elasticities, clustering by school.
Table S2 E-cigarette own- and cross-price elasticities, without cigarette prices.