NBER WORKING PAPER SERIES

THE EFFECTS OF E-CIGARETTE TAXES ON E-CIGARETTE PRICES AND TOBACCO PRODUCT SALES: EVIDENCE FROM RETAIL PANEL DATA

Chad D. Cotti
Charles J. Courtemanche
Johanna Catherine Maclean
Erik T. Nesson
Michael F. Pesko
Nathan Tefft

Working Paper 26724
http://www.nber.org/papers/w26724

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
January 2020, Revised April 2021

Author order is alphabetic and lead authorship is shared amongst all the authors. Research reported in this publication was supported by the National Institute on Drug Abuse of the National Institutes of Health under Award Number R01DA045016 (PI: Michael Pesko). There are no conflicts of interest. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research or the National Institutes of Health. We thank audiences at the University of Victoria Department of Economics (2021), Society for Research on Nicotine & Tobacco Conference (2021), Midwest Health Economics Conference (2020), Tobacco Online Policy Seminar (2020), Southern Economic Association Conference (2020), National Bureau of Economic Research Summer Institute Health Economics Program (2020), Society for Benefit-Cost Analysis Conference (2020), and Iowa State Department of Economics (2020) for helpful comments. We also thank Brant Callaway, Scott Cunningham, Dhaval Dave, Daniel Dench, Andrew Goodman-Bacon, Michael Grossman, Donald Kenkel, David Powell, Henry Saffer, Pedro Sant'Anna, Hunt Allcott, and Charlie Rafkin. Researcher(s) own analyses calculated (or derived) based in part on data from Nielsen Consumer LLC and marketing databases provided through the NielsenIQ Datasets at the Kilts Center for Marketing Data Center at The University of Chicago Booth School of Business. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research or the National Institutes of Health.

The Effects of E-Cigarette Taxes on E-Cigarette Prices and Tobacco Product Sales: Evidence from Retail Panel Data
Chad D. Cotti, Charles J. Courtemanche, Johanna Catherine Maclean, Erik T. Nesson, Michael F. Pesko, and Nathan Tefft
NBER Working Paper No. 26724
January 2020, Revised April 2021
JEL No. I1,I12

ABSTRACT

This paper estimates effects of e-cigarette taxes enacted in eight states and two large counties on e-cigarette prices, e-cigarette sales, and sales of other tobacco products. We use NielsenIQ Retail Scanner data from 2011 to 2017, comprising approximately 35,000 retailers nationally, and develop a method to standardize e-cigarette taxes since adopting localities have taxed these products in heterogeneous ways. We estimate a tax-to-price pass-through rate of 1.44 and a Herfindahl–Hirschman Index of 0.246 for e-cigarette retail purchases, indicating a moderately to highly concentrated market structure theoretically linked to tax over-shifting. We then calculate an e-cigarette own-price elasticity of -1.30 and positive cross-price elasticities of demand between e-cigarettes and cigarettes, suggesting they are economic substitutes. Other analyses explore heterogeneity in tax and price responses across flavored and non-flavored e-cigarettes and cigarettes.

Chad D. Cotti
Department of Economics
University of Wisconsin-Oshkosh
and Center for Demography of Health
and Aging
University of Wisconsin-Madison
cottic@uwosh.edu

Charles J. Courtemanche
Department of Economics
Gatton College of Business and Economics
University of Kentucky
Lexington, KY 40506-0034
and NBER
courtemanche@uky.edu

Johanna Catherine Maclean
Department of Economics
Temple University
Ritter Annex 869
Philadelphia, PA 19122
and NBER
catherine.maclean@temple.edu

Erik T. Nesson
Department of Economics
Ball State University
Muncie, IN 47306
and NBER
etnesson@bsu.edu

Michael F. Pesko
Department of Economics
Andrew Young School of Policy Studies
Georgia State University
PO Box 3992
Atlanta, GA 30302-3992
mpesko@gsu.edu

Nathan Tefft
Department of Economics
Bates College
Lewiston, ME 04240
ntefft@bates.edu

1. Introduction

According to the Centers for Disease Control and Prevention (CDC), nearly 3% of adults in the United States used electronic cigarettes (‘e-cigarettes’) in 2017 (Centers for Disease Control and Prevention 2018). Use of e-cigarettes (‘vaping’) among adolescents has grown even more rapidly, with nearly 27.5% of high school students using e-cigarettes in 2019 (U.S. Food & Drug Administration 2019). The rapid rise in vaping has led to concerns among public health officials and a focus on tobacco control policies aimed at curbing e-cigarette use. As of December 2020, 28 states have enacted an e-cigarette tax (Public Health Law Center 2020).

In this paper, we provide evidence of the effects of e-cigarette taxes on the prices and sales of e-cigarettes and other tobacco products using the NielsenIQ Retail Scanner Dataset (NRSD) over the years 2011 to 2017. The NRSD tracks weekly sales of a national panel of approximately 35,000 retailers and covers a large percentage of total sales among drug stores, mass merchandisers, food stores, dollar stores, and club stores.[1]

We first estimate the pass-through rate of e-cigarette and cigarette taxes to the prices of these goods, finding that e-cigarette taxes are more than fully passed through to e-cigarette prices. Specifically, we estimate that a $1.00 increase in e-cigarette taxes raises e-cigarette prices by about $1.44. We provide evidence that the e-cigarette retail-based market has shifted from one that is highly concentrated to one that is moderately concentrated, as evidenced by a Herfindahl-Hirschman Index values which fall from 0.36 in 2013 and 2013 to 0.18 in 2017. The over-shifting of taxes to prices is theoretically linked to imperfectly competitive markets (Besley and Rosen 1999).

[1] We use the NRSD instead of the NielsenIQ Consumer Panel Dataset because the NRSD provides approximately a 4.8% sample of national e-cigarette sales, whereas the NielsenIQ Consumer Panel Dataset covers only a 0.05% sample of e-cigarette sales (see Allcott and Rafkin (2020)).

Next, we estimate reduced-form models of the effects of e-cigarette and cigarette taxes on sales of each product, and then use the taxes as instruments to examine the own- and cross-price elasticities of demand for e-cigarettes and cigarettes. Estimates suggest an e-cigarette own-price elasticity of demand of -1.30. We find a cigarette own-price elasticity of -0.39, similar to previous estimates (for reviews, see Chaloupka and Warner 2000, DeCicca et al. 2018). Finally, we find consistent evidence that cigarettes and e-cigarettes are economic substitutes (cigarette cross-price elasticity = 1.1; e-cigarette cross-price elasticity = 0.45.). Recent theoretical work on the demand for nicotine motivates our results on the own- and cross-price elasticities of demand. In particular, Lillard (2020) develops a model suggesting that the demand for tobacco products is a derived demand based on the demand for nicotine. The choice of products is determined by the shadow price of nicotine from the product, which is determined by the cost of the product, the efficiency of nicotine delivery, and the health and social effects of different products. Depending on these factors, different categories of nicotine products could theoretically be complements or substitutes.

Our paper is among the first to estimate the pass-through rate for e-cigarette taxes. Examination of the intensive tax margin requires standardizing different forms of e-cigarette taxes to measure the magnitude of the tax. Standardization is complicated given heterogeneity in the ways localities have elected to tax e-cigarettes. Unlike cigarette taxes, which are typically calculated per unit, many e-cigarette taxes are levied as ad valorem taxes. Our paper develops a novel method to standardize e-cigarette taxes. Exploration of the intensive tax margin (which requires standardization) is important because the standardized magnitudes of existing e-cigarette taxes vary widely, from $0.05 per milliliter (ml) in Kansas and Louisiana to $1.81 per ml in Minnesota.

To estimate the pass-through rate of e-cigarette taxes to prices and a price elasticity of demand, we match e-cigarette Universal Product Codes (UPCs) available in the NRSD to liquid volume information hand-collected from internet searches, correspondences with companies, and visits to retailers. This hand-collected database also includes product type, liquid flavor, and nicotine content. These additional product characteristics allow us to standardize both e-cigarette taxes and products. In particular, different e-cigarette products may contain different levels of liquid as well as nicotine. We utilize the product characteristics to examine ml of fluid sold, instead of raw counts of products, to more accurately identify the effect of taxation on the unit that is taxed (liquid). Separately, we also study the effect of taxation on nicotine concentration.

Using the NRSD allows us to examine e-cigarette purchases that occurred in the general population much earlier than is possible with other datasets of which we are aware.[2] In particular, we track e-cigarette purchases beginning in 2011 in the NRSD, while surveys commonly used in the economics literature do not begin collecting e-cigarette use information until several years later (e.g., 2016 in the Behavioral Risk Factor Surveillance Survey and 2014 in the National Health Interview Survey). This earlier time period enables us to leverage additional policy variation and offer a more rigorous investigation of pre-treatment trends between localities that adopt and do not adopt an e-cigarette tax.

2. Literature Review

In a perfectly competitive market, the rate at which a tax change impacts the after-tax price (i.e., the 'pass-through rate') ranges from zero to one and is a function of demand and supply elasticities. The pass-through rate will be zero if consumers have perfectly elastic demand (suggesting that suppliers pay the full incidence of the tax) or one if consumers have perfectly

[2] The National Youth Tobacco Survey asks about adolescent e-cigarette use starting in 2011, however this dataset cannot be used to study the full population.

inelastic demand (consumers pay all the tax). However, over-shifting – when the pass-through rate is greater than one – is possible in imperfectly competitive markets (e.g. Stern 1987, Besley 1989, Hamilton 1999) and has been observed in the cigarette market. Besley and Rosen (1999) use data drawn from the American Chamber of Commerce Research Association to examine the effect of sales taxes on after-tax prices of 12 common consumer products. The authors find negative pass-through rate estimates for two of 12 products, pass-through rate estimates between zero and one for five of 12 products, and pass-through rate estimates of greater than one for five of 12 products (Besley and Rosen 1999).

Several more recent studies evaluate the effect of cigarette tax increases on cigarette prices. Lillard and Sfekas (2013) use state-level prices from the Tax Burden on Tobacco from 1995 to 2007 and estimate a pass-through rate of 1.03. DeCicca, Kenkel, and Liu (2013) use consumer-reported prices from the 2003 and 2006 to 2007 Current Population Survey Tobacco Use Supplements to estimate the pass-through rate of cigarette taxes to consumer prices ranging from 0.91 to 1.18, with some evidence that the pass-through rate is lower for higher intensity smokers. Rozema and Ziebarth (2017) use individual-level data on prices paid for cigarettes from 2001 to 2012 in a sample of low-income, food stamp eligible households and estimate a pass-through rate of 0.80. Hanson and Sullivan (2009) use micro-level data on cigarette prices from retail locations in Wisconsin and border states to evaluate the effects of large increases in cigarette taxes, estimating a pass-through rate between 1.08 and 1.17. Finally, Harding, Leibtag, and Lovenheim (2012) use Nielsen Homescan data for 2006 and 2007 to estimate a UPC-level cigarette tax pass-through rate of 0.85. Overall, their findings provide a series of cigarette tax pass-through rate estimates ranging from 0.80 to 1.18.

Researchers have also estimated pass-through rates for other 'sin goods:' alcohol and sugar-sweetened beverages. Several studies find that alcohol taxes are more than fully passed through to prices (Kenkel 2005, Shrestha and Markowitz 2016, Shang, Ngo, and Chaloupka 2020, Gehrsitz, Saffer, and Grossman 2020). Recently, Cawley et al. (2019) review 15 pass-through rate studies for sugar-sweetened beverages, concluding that trends in prices after nationwide tax implementations are in line with the hypothesis that prices rise by the full amount of the tax. However, local taxes generally have lower estimated pass-through rate, potentially due to tax evasion opportunities created by cross-border shopping.

At the time of writing, only two published papers estimate the effect of e-cigarette taxes using quasi-experimental methods. One paper uses the Behavioral Risk Factor Surveillance Survey and the National Health Interview Survey, and shows that higher e-cigarette tax rates reduce e-cigarette use and increase cigarette use (i.e., economic substitution), with symmetric effects for cigarette taxes (Pesko, Courtemanche, and Maclean 2020). A second paper by Saffer et al. (2020) uses the Tobacco Use Supplement of the Current Population Survey from 1992 to 2015, in conjunction with e-cigarette taxes in Minnesota (which adopted a tax in 2010 and then increased the tax from 35% to 95% in 2013) and synthetic control methods to assess how e-cigarette taxes impact adult smokers in a case study analysis. Estimates suggest that the e-cigarette tax rate increases adult smoking and reduces smoking cessation in Minnesota, relative to the synthetic control group, and imply an e-cigarette cross-price elasticity of current smoking participation of 0.13. Assuming a retailer markup of 33% over the wholesale costs, the authors estimate a tax pass-through rate of 1.33 in that state.

Our paper has several key differences from previously published studies on e-cigarette taxes: 1) we estimate tax pass-through for more than a single state, 2) we estimate the effect on sales rather than use (the latter measure can be subject to reporting error related to stigmatized goods such as tobacco products), 3) we examine heterogeneity in the e-cigarette price elasticity of demand by liquid flavors, and 4) we explore tax effects on a range of tobacco products.

Additionally, in a working paper Allcott and Rafkin (2020) estimate whether e-cigarettes and cigarettes are economic substitutes or complements. Using several U.S. survey data sources, the authors use the pre-2013 smoking propensities for 800 adult and 56 youth demographic cells to implement a shift-share strategy to examine what impact wide use of e-cigarettes starting in the year 2013 has on smoking trends. Coefficient estimates suggest some evidence of substitution.[3]

Allcott and Rafkin's working paper was written concurrently to and independently of ours and, while our primary objectives are notably different, there is some overlap in the contributions, for example, use of the NRSD. However, there are important differences in the nature of these contributions. First, their interest in the relationship between taxes and prices is as a first stage in an instrumental variable model estimating the price elasticity of demand for use in welfare calculations, rather than as an attempt to measure the pass-through rate. Accordingly, Allcott and Rafkin use a logarithmic, not linear, functional form for both taxes and prices, which implies that their estimate relates percentage changes in taxes to percentage changes in prices, which is not informative about over- versus under-shifting. One of our research objectives is to quantify the pass-through rate and explore the extent of tax shifting in e-cigarette retail markets. Second, they use the 2013 to 2017 NRSD whereas we use data over the period 2011 to 2017, allowing us to

[3] Allcott and Rafkin (2020) also estimate instrumental variable models to estimate cross-price elasticities. In Table 2, they find some evidence that cigarette prices are positively associated with e-cigarette sales. In Online Appendix Table A2, they examine the effect of e-cigarette prices on the demand for cigarettes. Here, they find evidence that higher e-cigarette prices increase sales of cigarettes, although these results are not robust to the inclusion of area-specific linear trends. However, as discussed in Meer and West (2016), inclusion of such trends can lead to a overcontrolling bias if the treatment variable leads to a change in the area-specific outcome trends. In such a case, adding area-specific trends to the regression model can 'control away' part of the causal effect that the researcher is seeking to estimate. Hence, we interpret findings based on regression models that include area-specific time trends with some caution.

examine longer pre-treatment trends for violations of the parallel trends assumption. Third, Allcott and Rafkin standardize e-cigarette taxes as ad valorem taxes, whereas we standardize the e-cigarette taxes as specific unit taxes by taking advantage of Washington DC and California's ad valorem tax that is set to parity with the cigarette tax. A contribution of our study is to estimate these elasticities and assess the extent to which various tobacco products are economic complements or substitutes. In sum, our papers complement each other's evidence on the relationship between e-cigarettes and cigarettes.

Pesko, Courtemanche, and Maclean 2020 also use an early version of the standardized tax methodology that was developed by this paper (and appropriately attributed). However, the method has been refined in the current paper by incorporating more wholesale price information than just Washington DC and additional hand-collected product characteristic data. The reasonable estimates of the effect of the early version of the standardized e-cigarette tax on adult tobacco product use in Pesko, Courtemanche, and Maclean (2020) support the validity of the method used in this paper.

3. Data

a. NielsenIQ Retail Scanner Data (NRSD)

Our main data source is the 2011 to 2017 NRSD. The NRSD comprises a sample of approximately 35,000 retailers, including grocery stores, drug stores, mass merchandise retailers, and other types of stores. In 2017, the NRSD included between 15% and 26% of all food store, mass merchandiser, dollar store, and club store sales, and over 50% of drug store sales. The NRSD contains a smaller percentage of sales in convenience stores and liquor stores (approximately 2% each). The weekly volume and average price paid for each UPC purchased at each store is recorded, including all taxes except sales taxes. E-cigarette products are identified by NielsenIQ, and we include only devices with liquid in our analysis sample (e.g., tank systems without liquid are not considered e-cigarettes). Each e-cigarette product has a unique UPC, and any change in the product triggers the creation of a new UPC. Therefore, UPCs are perfectly nested within brands and many brands have multiple UPCs for the numerous variations of e-cigarettes sold under a given brand.

For e-cigarette sales in the NRSD, we match hand-collected product characteristics by UPC. These data were collected from correspondence with e-cigarette companies, internet searches, and in-person visits to retailers conducted by members of the research team. The database was initially developed and used in Cotti, Nesson, and Tefft (2018). Product characteristic information allows us to accurately determine e-cigarette product type (i.e., disposable e-cigarettes, starter kits, and cartridge refills),[4] the milliliters (mls) of fluid in each e-cigarette UPC, and the flavor of the e-cigarette. We are able to match 96.3% of e-cigarette sales in the NRSD to tobacco product characteristics in this way. Given that nicotine is the primary ingredient sought by tobacco product consumers (Lillard 2020), we exclude a small number of e-cigarettes that do not contain nicotine (<0.1% of total e-cigarette sales).

For nicotine-containing e-cigarette sales in the NRSD, we construct sales-weighted e-cigarette prices at both the UPC-locality-quarter level and locality-quarter level. A locality is defined as a state or county (depending on the geographical extent of a tax) and a quarter refers to a quarter-by-year.[5] As discussed in Section 4, we use separate regressions for e-cigarette prices at

[4] Starter kits include a reusable battery and atomizer along with a selection of disposable cartridges.
[5] We estimate our model quarterly rather than monthly since our standardized e-cigarette tax measure uses market-level information that is more stable at the quarterly level, in particular during earlier years of our study period when we observe fewer e-cigarette sales.

these different levels of aggregation, to hold or not hold product quality constant (Harding, Leibtag, and Lovenheim 2012).

We aggregate sales data to the locality-quarter level for e-cigarettes, cigarettes, cigars, chewing tobacco, and loose tobacco. For e-cigarettes, we use our hand-collected data to create sales per fluid ml. For the other tobacco products, we create variables counting the sales for each product in terms of the units provided by NielsenIQ. We thus separately count the number of cigarette packs, the number of cigars, the ounces of chewing tobacco, and the ounces of loose tobacco sold.

We also separately analyze cartridge refills only, thus focusing more exclusively on liquid nicotine demand rather than combining nicotine with devices included in starter kits and disposables (Lillard 2020). When using cartridge-specific outcomes, we use a standardized e-cigarette tax constructed using a wholesale price of \$3.52 for cartridges in Minnesota (Saffer et al. (2020) rather than the wholesale price of \$4.35 for a sales-weighted basket of all e-cigarette products as determined by California and Washington DC tax authorities. These results, as we show later in the manuscript, are similar to our main estimation results.

b. Tobacco Control Policies

We use three policy data sources to construct our e-cigarette tax variable.[6] State-level e-cigarette tax data is drawn from the Public Health Law Center (Public Health Law Center 2020)

[6] The economic literature has moved towards using taxes, rather than prices, as the former are viewed as more exogenous after conditioning on observable characteristics (see Pesko, Courtemanche, and Maclean (2020) for a discussion of this issue). However, this focus does not imply that taxes are truly exogenous. Indeed, similar to all policies of which we are aware, taxes are developed within the local political economy (see Besley and Case (2000) for an excellent discussion of this issue). We provide suggestive evidence later in the manuscript that, after conditioning on observables and various fixed effects, our tax variable is plausibly exogenous. In particular, we estimate event studies and observe no evidence of differential pre-trends between adopting and non-adopting localities, we conduct balance tests, and apply falsification testing. Further, we include controls for political factors,

and the Centers for Disease Control and Prevention State Tobacco Activities Tracking and Evaluation (STATE) System (Centers for Disease Control and Prevention 2019b). We reconcile discrepancies by directly consulting the original state statutes. We collect sub-state e-cigarette tax data from the Vapor Products Tax website (Tax Data Center 2019). Through 2017, e-cigarette taxes are primarily levied through a unit tax on per ml liquid volume or through an ad valorem tax that is paid by the wholesaler or retailer. In our sample period, Kansas, Louisiana, North Carolina, West Virginia, Cook County Illinois, and Chicago Illinois levy a unit tax on liquid volume. California, Minnesota, Montgomery County, Pennsylvania, and Washington DC use an ad valorem tax. Chicago uses a unit tax on both liquid volume and the number of disposable or refill units sold. Several counties in the state of Alaska also levy e-cigarette taxes, but Alaska is not included in the NRSD through 2017 and is therefore not included in our standardization procedure or our analysis. Online Appendix Table 1 provides information on the effective dates, unit taxed, tax amount, and relative tax value (in 2017 quarter four) for each e-cigarette tax law implemented during the time frame of NRSD data utilized in this study.[7]

In Washington DC and California, the tax authorities determine the average wholesale price for a basket of all e-cigarette products sold in the locality and set the percent ad valorem tax to make the tax collection on the average e-cigarette product equivalent to the tax collection on a pack of cigarettes. We use this relationship to convert e-cigarette ad valorem taxes into unit tax

which may proxy the local political economy, and results are not appreciably different. In sum, while caution is always reasonable when using policies as a source of variation, our interpretation of a range of design testing suggests that our main results are not driven by the endogeneity of the tax variables.

[7] In unreported analyses, we incorporate tax adoptions that occurred after the end of our study period, i.e., those that occurred 2018 through 2021, in an event study. Results (available on request) are not appreciably different than those reported later in the manuscript. More specifically, we observe no evidence that our data violate the parallel trends assumption necessary for identification in two-way fixed-effects models.

equivalents for each relevant locality.[8] See the Data Appendix for a detailed discussion of our tax conversion algorithm.

We collect state-level data on cigarette unit taxes from the Centers for Disease Control and Prevention STATE System, and we supplement these data with population-weighted local cigarette taxes from the American Non-Smokers' Rights Foundation and federal cigarette tax data from the Tax Burden on Tobacco. Our cigarette tax measure therefore sums the state cigarette tax, local cigarette taxes (population-weighted to the locality level), and federal cigarette tax ($1.01 per pack). We transform these taxes into the cigarette unit taxes measured in real 2017 dollars (using the Consumer Price Index-Urban Consumers) in each locality and quarter (Centers for Disease Control and Prevention 2019b). We also control for population-weighted percent share of the population with Tobacco 21 laws in place, using data on all state and municipal Tobacco 21 laws provided by Tobacco21.org.

Additionally, we collect data on indoor air laws from the American Non-Smokers' Rights Foundation. The American Non-Smokers' Rights Foundation tracks when municipalities, counties, and states pass indoor air laws for vaping or smoking in different venues. We use this information to create two separate measures for the share of the population in each county living with indoor vaping restrictions and indoor smoking restrictions for private workplaces, restaurants, or bars. For both indoor vaping restrictions and indoor smoking restrictions, we consider only complete bans and weight laws applying to bars, restaurants, and private workplaces equally. We aggregate the county-level bans up to the state using population as a weight (such aggregation is

[8] For our e-cigarette tax measure, we use a wholesale price of $4.35 which is the average wholesale price for e-cigarettes determined by California and Washington DC tax authorities over our time period. We explore the sensitivity of our results to this assumption in a number of ways: 1) use a separate wholesale price of just $3.52 Saffer et al. (2020) for cartridge prices and sales, 2) use two separate variables for ad valorem tax rate and excise tax rate, which avoids any assumptions regarding standardization. However, this approach does not allow the coefficient estimates to be directly compared.

not necessary for Cook County and Montgomery County). Additionally, we use data on state laws banning smoking and vaping in K-12 public schools from the Centers for Disease Control and Prevention STATE system (Centers for Disease Control and Prevention 2019b).

4. Methods

Prices reflect a market equilibrium outcome, which is determined by both supply- and demand-side factors. We take a reduced form approach, which allows us to analyze the extent to which prices are passed through to consumers without making specific assumptions regarding the underlying e-cigarette market structure (Harding et al, 2012). We note that some scholars hypothesize a Cournot model to characterize the e-cigarette market (Saffer et al,2020), which is encompassed within our reduced form specification. The controls we include in our regression model (outlined below) are selected to proxy for salient market factors. We include locality-level demographics and policies, which likely shape demand for e-cigarettes which, in turn, impact equilibrium e-cigarette prices. Additionally, we include labor market and area-level controls that plausibly capture supply-side factors that impact e-cigarette production. We select our controls using insight drawn from previous economic studies that seek to estimate pass-through rates with reduced-form methods in American tobacco product markets (Lillard and Sfekas 2013, Harding, Leibtag, and Lovenheim 2012, Saffer et al. 2020).

We implement a standard two-way fixed effects identification strategy by leveraging within locality-level variation in e-cigarette and cigarette taxes that occurs between 2011 and 2017 to identify treatment effects. Specifically, we estimate the following regression model:

(1) $$Y_{i,l,t} = \beta_0 + \beta_E Etax_{l,t} + \beta_C Ctax_{l,t} + W_{l,t}\beta_W + X_{l,t}\beta_X + \sigma_{l,i} + \tau_t + \varepsilon_{i,l,t},$$

where $Y_{i,l,t}$ is the price for e-cigarette product (i.e., UPC) i in locality l and quarter-year t. We use 51 localities, one for each state and Washington DC (minus Alaska and Hawaii as these states are not in the NRSD), but separating Cook County from Illinois and Montgomery County from Maryland since these sub-state localities also adopt e-cigarette taxes during our study period. We aggregate $Y_{i,l,t}$ to the UPC-by-locality-by-quarter level by creating an average price for each UPC-locality-quarter, using each UPC's sales volume in localities that have not adopted an e-cigarette tax by the end of 2020 as the weight.[9] We measure both e-cigarette taxes ($Etax_{l,t}$) and cigarette unit taxes ($Ctax_{l,t}$). $Etax_{l,t}$ is a continuous variable measuring the magnitude of e-cigarette taxes as described in Section 3.b and the Data Appendix. $Ctax_{l,t}$ is a continuous variable measuring the locality-level cigarette unit tax per pack (i.e., summing across local, state, and federal taxes).

We include additional tobacco control policies in $W_{l,t}$: 1) a vector of indoor smoking restrictions and indoor vaping restrictions (measured as the percent of the locality's population living under an indoor smoking restriction, and separately as the percent of the locality's population living under an indoor vaping restriction), 2) state laws banning smoking and vaping in K-12 public schools, and 3) the percent share of all locality borders that do not have an e-cigarette tax (a proxy for tax avoidance propensity).[10] We also include locality-level characteristics in $X_{l,t}$: beer tax, Affordable Care Act Medicaid expansions,[11] Bureau of Labor Statistics' unemployment rate, and Current Population Survey demographics (e.g., age, sex, and race/ethnicity). We also include UPC-by-locality and quarter-by-year fixed effects in our

[9] We use only localities that do not adopt an e-cigarette tax to avoid weights that are potentially endogenous to the policy variable we study.

[10] As an additional strategy to compensate for tax avoidance, we re-estimate our models dropping counties that are within 50 miles of a reduced tax source as of the end of 2017 (approximately 50% of all counties that eventually have e-cigarette taxes). This includes dropping Cook County, Montgomery County, Washington DC, and many other counties near reduced-tax borders in states taxing e-cigarettes. Our results are consistent when dropping half of the eventual treatment counties. We discuss these results in Sections 5.a., 5.c., Table 4A, and Online Appendix Table 4A.

[11] https://www.kff.org/health-reform/state-indicator/state-activity-around-expanding-medicaid-under-the-affordable-care-act. Last accessed on 4/9/2021.

regression models, represented by $\sigma_{i,l}$ and τ_t, respectively, following Harding, Leibtag, and Lovenheim (2012). The product fixed effects hold product availability and quality[12] constant, thus allowing us to study the pass-through rate independent of manufacturers changing their mix of products offered for sale in response to e-cigarette taxes. Quarter-by-year fixed effects account for time-varying national level factors such as social media advertisements. We cluster standard errors at the locality level in all specifications (Bertrand et al., 2004), and we weight the data by the share of e-cigarette sales in localities that do not adopt an e-cigarette tax by 2017. We demonstrate that our main findings are robust to a number of alternative specifications, as well as different analytical samples, weighting schemes, and aggregations. We convert all monetary variables included in the analysis to 2017 dollars using the Consumer Price Index.

After examining the pass-through rate of e-cigarette taxes to e-cigarette prices, we next examine whether e-cigarette and cigarette prices affect sales of tobacco products. In these models, we aggregate our data to the locality-by-quarter level for each category of tobacco products, which is different from the UPC-by-locality-by-quarter aggregation in equation (1) to permit new product offerings to be reflected in tax responsiveness. Our approach closely follows Harding, Leibtag, and Lovenheim (2012).[13]

We examine five categories of tobacco products: e-cigarettes, cigarettes, cigars, chewing tobacco, and loose tobacco. We also analyze non-flavored and flavored e-cigarettes and cigarettes separately. To this end, we separate e-cigarettes into three flavored categories using our hand-

[12] Faced with a tax change, manufactures could either raise prices or reduce the quality (and costs) of their product, such as by using a less esthetically pleasing exterior or lower quality flavor ingredients in the context of e-cigarettes, or lower-quality tobacco in the context of cigarettes. As noted in Section 3.a, any notable change in a tobacco product would trigger a new UPC in the NielsenIQ. Therefore, holding product quality constant by including UPC fixed effects in our regression models allows us to isolate the effect of taxes on consumer prices.

[13] The authors estimate a UPC fixed effects model to calculate pass-through in order to study tax-to-price pass-through while accounting for the possibility that producers may change the quality of cigarettes available on the market in response to the tax. Separately, Harding et al estimate locality (i.e., state) fixed effect models for sales outcomes to avoid restricting cigarette products to those UPCs existing both before and after the tax.

collected product characteristics data: 1) tobacco flavored e-cigarettes (non-flavored); 2) mint and menthol flavored e-cigarettes; and 3) other flavors (which may include fruit, chocolate, coffee, etc.). We separate cigarettes into regular cigarettes and menthol cigarettes using flavor information available in the NRSD.

For e-cigarette products, our unit of measure is milliliters of liquid purchased in order to match the units of our standardized tax variable. We examine counts of the products purchased for other tobacco product categories. We estimate a similar model to that reported in equation (1), but at the locality-by-quarter level:

(2) $$Y_{l,t} = \gamma_0 + \gamma_E Etax_{l,t} + \gamma_C Ctax_{l,t} + W_{l,t}\gamma_W + X_{l,t}\alpha_X + \delta_l + \chi_q + \mu_{l,t},$$

Here, $Y_{l,t}$ represents sales of a tobacco product in locality l and time t, and the other variables are the same as in equation (1). We estimate sales in levels because we did not observe evidence of curvature in the relationship between e-cigarette taxes (which are predominantly zero since few states have e-cigarette taxes) and e-cigarette sales.[14] We weight equation (2) regressions using locality population and cluster standard errors at the locality level.

We also study the impact of prices on tobacco product purchases. A potential empirical problem with estimating this relationship is that e-cigarette and cigarette prices are endogenously determined. Put differently, prices are determined by demand- and supply-factors that are difficult to fully capture with observable characteristics available in data. For example, underlying preferences for nicotine and harm reduction among consumers which would shape e-cigarette demand, and labor market structure (e.g., perfect competition, monopsony) which would impact

[14] We use Stata's *semipar* command (Robinson 1988). Such evidence would support log-transforming the dependent variable. More specifically, in order to log-transform the e-cigarette tax variable, we would need to add a positive value to the vast majority of our data given that e-cigarette taxes are recent policy changes, thereby substantially altering the tax data. Recent work suggests that alternative methods such as the inverse hyperbolic sign transformation do not perform well (Mullahy 2021).

wages paid to workers involved with producing and selling e-cigarettes. Therefore, we simultaneously instrument for e-cigarette and cigarette prices using e-cigarette and cigarette taxes in the two-stage least squares (instrumental variable) regression:

(3) $$Y_{l,t} = \alpha_0 + \alpha_E \widehat{EP}_{l,t} + \alpha_C \widehat{CP}_{l,t} + W_{l,t}\alpha_W + X_{l,t}\alpha_X + \delta_l + \chi_q + \epsilon_{l,t},$$

where $EP_{l,t}$ and $CP_{l,t}$ are replaced with their predicted values, $\widehat{EP}_{l,t}$ and $\widehat{CP}_{l,t}$, from first stage regressions. Our identifying assumption is that e-cigarette and cigarette taxes affect demand only through their effects on e-cigarette and cigarette prices. Thus, we assume that there are no other channels though which taxes can influence sales, e.g., that there is no signaling of product risk.

5. Results

a. Summary Statistics

We begin by showing summary statistics and the variation in e-cigarette taxes. Table 1 shows summary statistics at the UPC-locality-quarter level. Overall, our sample has 91,299 UPC-locality-quarter observations, of which 9,763 are subject to an e-cigarette tax. The average e-cigarette price per ml of liquid is \$4.35, and the average price is slightly higher in localities that adopt an e-cigarette tax (measured before the tax is imposed) than in localities that did not adopt a tax by the end of our study period (\$4.46 vs. \$4.29). The conditional (non-zero) mean e-cigarette tax is \$0.67 per fluid ml. The unconditional mean is \$0.04 per fluid ml. The unconditional mean is markedly lower than the conditional mean as many localities do not adopt a tax during our study period, and those localities that adopt a tax implement this policy during the latter portion of our study period. Unit taxes are generally smaller in magnitude than ad valorem taxes, with the conditional mean value of unit taxes being \$0.21 and ad valorem taxes being \$1.02. These differences underscore the importance of accounting for the size of the tax in empirical analyses, which we are able to do through our standardization algorithm. The cigarette tax is $2.69 over our study period, which reflects the imbalance in taxation of the two tobacco products.[15]

Table 2 shows summary statistics for our sample when aggregated to the locality-by-quarter level. This sample includes 1,428 locality-by-quarter observations, of which 185 are subject to an e-cigarette tax. E-cigarette sales are much lower in localities that adopt an e-cigarette tax, and this is true for cigarettes, cigars and loose tobacco as well (but not for chewing tobacco). These descriptive statistics also show only 14% of locality-quarter observations are covered by an indoor vaping ban, while cigarette indoor smoking bans are much more prevalent (69%). Across our sample, about 43% of e-cigarette liquid purchased is tobacco flavored, while between 27% and 29% are menthol flavored or have other flavors. The majority of liquid purchases, about 60%, are in refill cartridges, followed by disposable e-cigarettes at 25% and very few starter kits. Cigarettes are also heavily weighted towards tobacco flavor, with menthol cigarettes making up only 25% of cigarette sales. The distribution of sales between product types is relatively constant across localities that do and do not adopt an e-cigarette tax.

Figure 1 displays the geographic and dollar variation in our standardized e-cigarette tax measure at the end of our sample period in the 4th quarter of 2017 (additional details are also provided in Online Appendix Table 1). Kansas, Louisiana, North Carolina, and West Virginia have unit tax values of between $0.05 to $0.075 per fluid ml, and California, Minnesota, and Pennsylvania have ad valorem tax rates of between 40% to 95%. Thus, the higher standardized tax values in the ad valorem tax states reflect the much larger magnitude of these taxes.

[15] Table 1 clearly shows that e-cigarettes are taxed at a relatively lower rate that cigarettes during our study period. In our empirical models, we identify direct and substitution effects using within-locality variation in both taxes. The impact of relative level differences is unclear *ex ante*

Figure 2 displays trends in e-cigarette and cigarette taxes from 2011 to 2017. We calculate the population-weighted tax rates for e-cigarettes in dollars per fluid ml and cigarette taxes in dollars per pack for each year. Both e-cigarette and cigarette taxes increase over our study period. E-cigarette taxes per fluid mL are low through 2017, rising from nearly zero dollars in 2011 to about $0.17 in 2017. Cigarette taxes rise from about $2.50 per pack in 2011 to nearly $2.95 in 2017.

b. Herfindahl–Hirschman Index

Since the pass-through rate of taxes to prices in part depends on market concentration, we examine the degree of concentration in e-cigarette retail markets over our study period by calculating the sample Herfindahl–Hirschman Index. We use 100% of the e-cigarette products identified in the NRSD[16] to identify 81 unique e-cigarette companies.[17] Sixteen companies sold e-cigarettes in NRSD-participating retailers in 2011, 29 in 2012, 45 in 2013, 52 in 2014, 56 in 2015, 48 in 2016, and 43 in 2017.

Using data from these companies, the annual Herfindahl–Hirschman Index values are 0.293 (2011), 0.357 (2012 and 2013), 0.217 (2014), 0.157 (2015), 0.165 (2016), and 0.177 (2017). The mean Herfindahl–Hirschman Index over the full time period is 0.246 and this has declined by 56% between 2012 and 2015, before beginning to rise again in 2016 and 2017. An Herfindahl–Hirschman Index value of over 0.25 is classified as a highly concentrated industry, and an Herfindahl–Hirschman Index value between 0.15 and 0.25 is a moderately concentrated industry (U.S. Department of Justice 2010). E-cigarettes have therefore sold in a highly concentrated retail

[16] NielsenIQ categorizes specific UPC codes as e-cigarettes beginning in 2013. We identify e-cigarettes in 2011 and 2012 as those categorized by NielsenIQ as e-cigarettes in 2013 and after. For our calculation of the Herfindahl-Hirschman Index we use all e-cigarettes categorized by NielsenIQ rather than the 96.3% matched to additional characteristics, after excluding e-cigarettes without nicotine.

[17] We group brands produced by the same company together.

setting from 2011 to 2013 and have been sold in a moderately to highly concentrated retail setting from 2014 to 2017. This finding suggests an imperfect level of market competition, which is relevant to our main results, as imperfect competition has been theoretically linked to over-shifting of taxes to prices (Besley and Rosen 1999).[18]

The Food and Drug Administration, the federal government agency within the U.S. that has the authority to regulate tobacco products, 'deemed' e-cigarettes a tobacco product in August 2016 and required e-cigarette companies to eventually submit Premarket Tobacco Product Applications. The market began to concentrate again in 2016, potentially because the Premarket Tobacco Product Applications process was too costly for small manufacturers, which could theoretically generate higher consumer prices and tax pass-through rates.

c. Estimates of E-Cigarette Tax Pass-through Rate

We first present results estimating the effects of e-cigarette taxes on e-cigarette prices. Table 3 presents results estimating equation (1), where the unit of analysis is a UPC-locality-quarter and the dependent variable is e-cigarette price. Moving from left to right in the table, we begin with a parsimonious specification that only includes e-cigarette taxes and cigarette taxes, then we add locality and quarter fixed effects, time-varying controls, and finally we replace the locality fixed effects with UPC-by-locality fixed effects in the last column.[19] Presenting the results in this manner also allows us to conduct a test of confounding in the spirit of Altonji, Elder, and

[18] Agrawal and Hoyt (2019) show that over-shifting can occur even in a perfectly competitive market if the product being taxed has a sufficiently strong substitute. Consider a market with two substitute goods A and B. A feedback loop occurs in which a tax on good A shifts out demand for good B, which in turn increases the price of good B, which increases the demand for good A, thereby increasing its price even further. The initial effect might only give a pass-through rate of one (or less), but the feedback loop ultimately leads to a price response of greater than one-for-one.

[19] In a model with only locality and quarter fixed effects, the within R-squared is 0.0216, between R-squared is 0.0120, and overall R-squared is 0.0223.

Taber (2005): coefficient estimates that are relatively robust to different sets of controls offer suggestive evidence that confounding is not driving the findings.

We find that every \$1.00 increase in e-cigarette taxes raises e-cigarette prices by over \$1.23 in all regressions and between \$1.44 and \$1.58 in the specifications with fixed effects. These estimates are all statistically significantly different from zero (and from one) at the 1% level. We therefore find robust evidence that e-cigarette taxes are over-shifted to consumers. Changes in cigarette taxes do not lead to statistically significant changes in e-cigarette prices, and the coefficient estimates are small in magnitude across specifications.

The estimated pass-through rate is in line with previous work on other 'sin goods,' which suggests that taxes are passed through at a higher than 100% level, e.g., alcohol and sugar-sweetened beverages (Kenkel 2005, Cawley et al. 2019). Saffer et al. (2020) calibrate a Cournot model to closely match the 2015 retail e-cigarette price in Minnesota, thus estimating a pass-through rate of 1.33 that is very close to our estimate of 1.44. As discussed above, our Herfindahl–Hirschman Index calculation suggests a high degree of market concentration, supporting the notion that the retail-based e-cigarette industry is imperfectly competitive, a market environment susceptible to over-shifting of taxes to prices.

Next, we estimate event study models to test the parallel trends assumption of our two-way fixed effects models, to address potential concerns regarding policy endogeneity and to examine whether there are anticipatory price increases. The optimal event study approach is not immediately clear since our analysis presents a number of deviations from the canonical event study with a binary treatment variable that follows a staggered rollout pattern across localities. Our treatment variable is a continuous variable, and some of the 'treatments' are tax decreases. Relatedly, some localities have multiple treatment changes within our study period.

We therefore take two approaches to specifying an event study model. First, we examine changes in e-cigarette prices around changes in e-cigarette taxes. We dichotomize our e-cigarette tax variable and include only the first tax change within each state (ignoring any post-tax changes either due to inflation or due to future tax changes and simply consider the extensive margin of taxation). We then construct 16 quarter leads, i.e., interactions between an indicator variable for a tax adopting state and the time-to-event, and four quarter lags around the event. Periods (quarter-years) more than 16 (four) quarters in advance (after) the effective date are included in the -16 (+4) bin (similar to Sandler and Sandler (2014)). All non-adopting localities are coded as zero for event-time bins. We then treat the period at least 16 quarters before the tax adoption as the omitted period to be able to examine any anticipatory effects in price adjustments. That is, we normalize the 16 or more quarters pre-tax indicator to zero and use this time period as the index category to which all other lead and lag variables are compared.

Second, we follow an approach developed by Cotti, Nesson, and Tefft (2018) in a study of cigarette taxes, which is also similar to event study models reported in Allcott and Rafkin (2020). Similar to our setting, Cotti, Nesson, and Tefft (2018) examine a continuous treatment variable that both increases and decreases, and for which some localities experience multiple changes over the study period. More specifically, we consider all changes to the nominal e-cigarette tax rate attributable to policy changes (i.e., we do not incorporate changes due to inflation) and model future and past changes for each adopting locality. We include legislated changes that occur 16 periods in the future through four periods in the past; these variables are similar to lead and lag indicators in a standard event study, although we use the value of the nominal tax change and incorporate multiple changes within-locality. For example, in California in quarter two 2013 and quarter three 2013, the e-cigarette tax nominal changes that occur 16 periods in the future in this state are \$0.50 and \$0.71 respectively. The \$0.50 change is attributable to the state's initial tax of \$0.50 effective quarter two 2017 and the second change is attributable to the legislated tax increase from \$0.50 to \$1.21 effective quarter three 2017. All non-adopting localities are coded as zero for event-time bins. The omitted category, as in our canonical event study, is the period (quarter-year) ≥16 quarters prior to the event.

Figures 3 and 4 shows the results from these event study analyses. Figure 3 uses event-time bins indicating the effective date of any e-cigarette tax, whereas Figure 4 uses future and past nominal tax changes in the standardized e-cigarette tax amount. As both event studies illustrate, there is no evidence of a differential trend in e-cigarette prices in adopting and non-adopting localities prior to the tax increase. In the quarter after the tax increase, the coefficient estimate increases and stabilizes between 0.33 and 0.45, suggesting that the *implementation* of an e-cigarette tax (without consideration of the tax magnitude) raises prices by \$0.33 to \$0.45, on average. When considering the size of the e-cigarette tax change in Figure 3, the coefficient estimate increases from \$1.25 in the quarter after the tax increase to over \$2.00 in the final event-time bin one year and more after the tax change. Coefficient estimates on the policy lags are statistically different from the coefficient estimate for the period of tax adoption, which suggests that effects increase as time passes. This supports the notion that e-cigarette taxes are a source of exogenous variation in prices.

We also test the robustness of our results in a number of ways. Tables 4A and 4B list results from a number of specification tests. In Table 4A, we test the robustness of our results to various changes in our sample. First, we exclude U.S. Census divisions[20] that do not include any localities with an e-cigarette tax by the end of our study period, use forward imputation for missing e-

[20] We use the U.S. Census nine division classification.

cigarette prices for localities with zero sales for a given UPC code, drop the enactment period of each e-cigarette tax change, and drop years prior to 2013 (i.e., the time period prior to NielsenIQ adding a specific UPC category for e-cigarettes) from the analysis sample. Results are broadly similar and suggest over-shifting of taxes to prices.

Next, we further explore whether there is heterogeneity in the estimates between state vs. local and ad valorem vs. unit tax variation. One potential issue is that some taxes are levied at the state level and others at the county level. A second issue is that ad valorem taxes are standardized to be equated as unit taxes.

To address these issues, we estimate separate regression models that use 1) state-level variation in taxes, i.e., drop treated counties within states, and 2) sub-state variation in taxes, i.e., drop treated states. Our results here suggest that state-level e-cigarette taxes are passed through to prices at a higher level than e-cigarette taxes enacted at the sub-state level, potentially because local-level taxes are easier to evade and, hence, the retailer has less ability to pass on taxes to prices in these markets. We bootstrap the difference in the coefficient estimates using a parametric bootstrap (500 repetitions). The difference is statistically significant at the 1% level. Relatedly, there is a potential difference in the pass-through rate from increases in excise taxes and ad valorem taxes. To this end, we explore pass-through rates for localities with ad valorem taxes versus only localities with excise taxes. Our results suggest that a \$1.00 increase in excise taxes causes a \$0.86 increase in prices and a \$1.58 increase for ad valorem taxes.[21] As shown in Online Appendix Table 1, state excise taxes are small (ranging between \$0.05 to \$0.20 per fluid ml) compared to ad valorem taxes, and so pass-through rates may be lower for excise taxes because of menu costs and/or retailers preferring to maintain psychological pricing (e.g., selling an e-cigarette for \$6.99

[21] Alternatively, each 1% ad valorem tax increases e-cigarette prices by \$0.03. As shown in Online Appendix Table 1, e-cigarette ad valorem tax rates range from 27.3% to 95%.

versus $7.04). Ad valorem taxes, however, may be sufficiently high such that retailers are forced to fully respond.

Finally, at the bottom of Table 4A we drop counties for all periods that are within 50 miles of a reduced tax source as of the end of 2017. This includes dropping Cook County, Montgomery County, Washington DC, and many other counties near reduced-tax borders in states taxing e-cigarettes. Our pass-through estimate of 1.56 is slightly larger but similar to our preferred pass-through estimate from Table 3 using all treatment counties of 1.44.

Next, we systematically drop treatment localities to examine whether any single treated locality has an outsized impact on our coefficient estimates. These results, shown in Online Appendix Table 2, suggest that our results are stable when removing individual treatment localities.

Table 4B shows results from different model specifications for the same sample. First, our results are robust to adding Census division-by-quarter and UPC-by-quarter fixed effects as well as using different weights. Next, we use an alternative standardized e-cigarette tax variable that uses the ratio of total units to total fluid volume specific to each treated locality for the standardization exercise, ignoring endogeneity concerns.[22] We also lag the e-cigarette tax variable by one quarter and one year to allow for dynamic effects, and include additional variables measuring political climate to further limit potential political endogeneity. We control for the political party of the Governor (University of Kentucky Center for Poverty Research 2021) and the state government ideology index (Berry et al. 1998).[23] Finally, we examine only refills (rather

[22] Our main measure uses the ratio specific to localities without e-cigarette taxes to remove endogeneity concerns.
[23] Data available here: https://rcfording.com/state-ideology-data/ (last accessed 4/20/2021). Washington DC is not a state and thus political variables are not defined. Following Maclean and Saloner (2018) we treat the Mayor of Washington DC as the de factor Governor of that locality. We assign the most liberal government ideology score observed in the empirical distribution to Washington DC. Results (available on request) are robust to excluding Washington DC. We assign counties the value of their state.

than starter kits and disposables) in our tax pass-through analysis. Results across this table are broadly similar and suggest over-shifting of taxes to prices.

Finally, we conduct a falsification exercise. In particular, we randomly re-assign the e-cigarette taxes across localities and estimate equation (1) 100 times, generating 'placebo' estimates. The randomization process re-shuffles each locality-quarter/year (period) independently across localities and across periods. If we are capturing a 'true' causal effect of e-cigarette taxes on e-cigarette prices, and not some other unobserved factor or policy, we would expect our main coefficient estimate to be an outlier relative to all placebo estimates. We report our placebo testing in Appendix Figure 1. Depicted as a dark diamond, our main coefficient estimate is an outlier.

d. Estimates of Effects of E-Cigarette Taxes on Tobacco Product Sales

Next, we examine the effects of e-cigarette and cigarette taxes on the sales of e-cigarettes and other tobacco products. For these analyses, we examine sales at the locality-by-quarter level with a reduced form model.

We conduct a covariate balance analysis in Online Appendix Table 3 (Pei, Pischke, and Schwandt 2019). This analysis demonstrates that, to a large degree, localities with and without e-cigarette taxes are similar in terms of the included variables. One notable difference is that cigarette taxes are much higher in localities with e-cigarette taxes.

Tables 5A and 5B show the results of these models across e-cigarettes and cigarettes. In the last column of Table 5A, every $1.00 increase in e-cigarette taxes reduces e-cigarette sales by about 750 ml. This suggests that a 1% increase in e-cigarette taxes leads to a 0.41% decrease in e-cigarette sales. Conversely, each dollar increase in cigarette taxes increases e-cigarette sales by 370 ml, so each 1% increase in cigarette taxes leads to a 0.87% increase in e-cigarette sales.

Turning to cigarette sales in Table 5B, we observe a similar pattern of economic substitution between cigarettes and e-cigarettes. Here, a 1% increase in cigarette taxes reduces cigarette sales by about 0.27% while a 1% increase in e-cigarette taxes increases cigarette sales by about 0.14%.[24]

Online Appendix Tables 4A and 4B demonstrate that our e-cigarette tax findings in Tables 5A and 5B are robust to various samples and estimation strategies, including dropping counties for all periods that are within 50 miles of a reduced tax source as of the end of 2017. The only exception to finding a negative and statistically significant effect of e-cigarette taxes on e-cigarette sales is when we use only refills in calculating e-cigarette taxes, though the coefficient estimate as a percent of its year-prior mean is nearly identical to the baseline result in Table 5A. In Online Appendix Table 5 we show that results are insensitive to excluding one treatment locality at a time.

Tables 6A, 6B, and 7 examine sales responses by e-cigarette and cigarette flavor, sales of other tobacco products, and sales of e-cigarettes with other characteristics. Age is strongly predictive of e-cigarette flavor use. According to the 2014-15 Population Assessment of Tobacco and Health (PATH) data, 74% of adults 25 years of age and older used tobacco or mentholated/mint flavored e-cigarettes compared to only 42% of 18 to 24 year olds and 36% of 12 to 17 year olds (Soneji, Knutzen, and Villanti 2019). Thus, studying the effect of e-cigarette prices on sales of flavored e-cigarettes can allow us to explore heterogeneity in price responsiveness by age to some extent. In Table 6A, we find that sales of all flavor categories of e-cigarettes and cigarettes respond to changes in both cigarette and e-cigarette taxes. Specifically, we find that a 1% increase in e-cigarette taxes decreases non-flavored, menthol, and flavored e-cigarette sales by about 0.47%, 0.45%, and 0.29%, while increasing tobacco cigarettes and menthol cigarette sales

[24] To calculate the tax elasticities, we multiply the coefficient estimates from Table 6A and 6B by the mean tax rates conditional on a state passing a tax and divide by the average year-prior pre-tax sales. Thus, -0.41=-756*0.71/1307, 0.87=371*2.79/1194, -0.28=-6970*2.79/70,079, and 0.14=11,329*0.71/56,470.

by 0.13% and 0.19%. A 1% increase in cigarette taxes increases non-flavored, menthol, and flavored e-cigarette sales by about 0.77%, 0.74%, and 0.94%, while decreasing tobacco cigarettes and menthol cigarette sales by 0.23% and 0.44%. In Table 6B, we do not see statistically significant relationships between e-cigarette or cigarette taxes and sales of cigars, chewing tobacco, or loose tobacco.

Table 7 examines whether e-cigarette and cigarette taxes lead to increases in the number of new e-cigarette products sold in localities, the average liquid per unit, or the nicotine percentage of the liquid. While we do not find statistically significant changes in e-cigarette products or average liquid amounts, we do see that e-cigarette taxes increase the average nicotine strength of e-cigarette products purchased, which is a plausible mechanism to deliver nicotine to consumers free of taxes when nicotine is assessed per liquid volume in many localities rather than per nicotine concentration. This finding supports the importance of nicotine in consumer purchasing decisions, as emphasized by Lillard (2020).

Our falsification exercise (in which we randomly re-shuffle e-cigarette taxes) is shown in Appendix Figure 2 and 3, suggesting that the effect of e-cigarette taxes on e-cigarette and cigarette sales are outliers relative to all placebo estimates. Finally, Figure 5 provides event studies of e-cigarette and cigarette sales in the quarters before and after an e-cigarette tax increase, using future and past nominal tax changes in the standardized e-cigarette tax amount. As both event studies illustrate, there is no evidence of a differential trend in e-cigarette or cigarette sales in adopting and non-adopting localities prior to the tax increase. There is evidence of decreases in e-cigarette sales and increase in cigarette sales in the post-period.

e. Estimates of Effects of E-Cigarette Prices on Tobacco Product Sales

We now estimate an instrumental variable model where we instrument for e-cigarette prices and cigarette prices with e-cigarette taxes and cigarette taxes (equation 3). Relative to the reduced form models estimated thus far, instrumental variable analysis requires the additional assumption that taxes only influence sales via prices (i.e., the exclusion restriction). We cannot completely rule out the possibility that taxes influence sales through mechanisms besides prices, such as signaling about health risks, in which case the instrumental variable estimates would be overstated.

Table 8 reports instrumental variable regression results, which largely confirms our reduced form results.[25] We find that a \$1.00 increase in e-cigarette prices reduces e-cigarette sales by roughly 29% of the mean, while a \$1.00 increase in cigarette prices reduces cigarette sales by roughly 7% of the mean. These coefficient estimates translate into own-price elasticities of roughly -1.30 and -0.39, respectively.[26] The cigarette price elasticity is in line with many previous estimates of the price elasticity of demand for cigarettes (Chaloupka and Warner 2000, DeCicca et al. 2018, DeCicca, Kenkel, and Lovenheim 2020).

Our instrumental variable results again suggest that e-cigarettes and cigarettes are economic substitutes, evident in the positive and statistically significant effect of e-cigarette prices on cigarette sales (and vice versa). A 1% increase in the price of cigarettes increases e-cigarette sales by 1.11%, while a 1% increase in the price of e-cigarettes increases cigarette sales by 0.45%.[27] The larger cigarette cross-price effect may be due to this market being substantially larger than the e-cigarette market, hence relative changes in the price in the larger market (cigarettes) may have a disproportionate effect on potential purchasing in the smaller market (e-cigarettes).

[25] As described in Table 8, 1st stage F-statistics are 80.70 for e-cigarette prices and 661.83 for cigarette prices for our full sample.
[26] Here, -1.30=-378*(4.49/1,307) and -0.39 = -4,820*(5.73/71,042).
[27] Here, 1.11=233*(5.73/1,208) and 0.45 = 5,707*(4.49/56,470).

Results remain similar when excluding ad valorem or excise tax localities, with the exception of cigarette prices being less predictive when excluding ad valorem localities.

Tables 9 and 10 display results for different e-cigarette and cigarette flavors and other tobacco products. In Table 9, we again document interesting heterogeneity in price elasticities of demand. With a price elasticity of -0.90, flavored e-cigarettes are less elastic than tobacco or menthol flavored e-cigarettes (-1.57 and -1.50, respectively). The cigarette price elasticity of -0.28 is much less elastic than the price elasticity for menthol cigarettes (-0.71). The effect of cigarette prices on sales of e-cigarettes are largest for flavored e-cigarettes, with a 1% increase in cigarette prices leading to a 1.09%, 1.05%, and 1.22% increase in tobacco, menthol, and flavored e-cigarette sales. Similarly, the cross-price elasticity between e-cigarette prices and cigarette sales is largest for menthol cigarettes, where a 1% increase in e-cigarette prices leads to a 0.4% increase in non-flavored cigarette sales and a 0.62% increase in menthol cigarette sales.

Next, we explore the effect of prices on sales of other tobacco products: cigars, chewing tobacco, and loose tobacco. Results are listed in Table 10. We do not find any statistically or economically significant effects of cigarette or e-cigarette price changes on sales of the other tobacco products.

Finally, we re-estimate our instrumental variable model in equation (3), systematically dropping treatment localities to examine whether any single treated locality has an outsized impact on our coefficient estimates. These results shown in Online Appendix Table 6 suggest that our results are stable when removing individual treatment localities.

6. Discussion

In this paper, we examine the effects of e-cigarette taxes on e-cigarette prices, e-cigarette sales, and other tobacco product sales. We find that e-cigarette taxes are over-shifted to consumer prices, which is most likely in a market with high concentration, as suggested by our Herfindahl–Hirschman Index calculation. We also find that e-cigarettes are an elastic good, with an estimated price elasticity of demand of -1.30. We estimate that e-cigarettes and cigarettes are economic substitutes.

In late February 2020, the U.S. House of Representatives approved a national e-cigarette tax proportional to the federal cigarette tax (House Bill 2339 2020). The bill specifies a tax rate of \$50.33 per 1,810 milligrams of nicotine (or \$0.028 per milligram). JUUL pods at the time of writing contain 59 milligrams/ml (at 5% nicotine volume) and 0.7 fluid ml. Assuming this conversion, we simulate that, if this bill were to become law, the tax could raise e-cigarette prices by \$2.36 per ml (\$0.0278 x 59 x 1.44 using Table 3), would reduce NRSD e-cigarette ml purchases by 756 per 100,000 adults (using Table 5a), and would increase NRSD cigarette pack purchases by 11,329 per 100,000 adults (using Table 5b). Our rate of substitution would be halved when compensating for the NRSD capturing roughly twice the share of cigarette sales than e-cigarette sales, which brings us to a substitution rate of one pod = 5.5 packs.[28]

Our finding that there is a marked substitution response may be explained by several factors. First, a randomized controlled trial in England demonstrates that e-cigarettes are nearly twice as effective as existing nicotine replacement therapy at achieving one-year cigarette abstinence: 18.0% versus 9.9% (Hajek et al. 2019). This high effectiveness of e-cigarettes occurs despite England capping e-cigarette nicotine content at no more than 20 milligrams/ml (CNN

[28] 5.5 = 11,329 / (756 / 0.7) x 50%. Tax-paid cigarette sales is provided by Tax Burden on Tobacco reports, and e-cigarette sales is provided by a Cowan financial report. The issue of the NRSD capturing different shares of the cigarette and e-cigarette market should not be a threat to accurately estimating cross-elasticities, since the baseline level of sales will reflect the relative proportion of each market in the NRSD.

2019), which is only one third of JUUL's nicotine concentration of 59 milligrams/ml (at 5% nicotine). American e-cigarettes contain more nicotine and may therefore be more effective smoking cessation products, as nicotine is the product ultimately demanded by tobacco product consumers (Lillard 2020). Second, e-cigarettes are more widely used for smoking cessation than nicotine replacement therapies, e.g., 32% of current and past-year former smokers used e-cigarettes as their single method to quit smoking, compared to 18% using an nicotine replacement therapy (Rodu and Plurphanswat 2017). Finally, a sizable share of young adults purchasing cigarettes from retail-based locations may have already been impacted by e-cigarette availability; analysis of the 2011 National Youth Tobacco Survey shows that 3.3% of youth had already used e-cigarettes in their lifetime. That e-cigarettes help prevent or reduce cigarette use among young adults may be a substantial factor in generating a high rate of substitution. Our high rate of substitution also appears consistent with financial reporting statements made by Philip Morris that claims cigarettes may disappear from some countries within the next ten to 15 years (Lester 2020).

A limitation of our study is the reliance on e-cigarettes sold through retail stores, so we cannot capture e-cigarettes sold through specialty vape shops and online. One study estimates that in 2015, 40% of e-cigarette sales occurred in retail stores similar to those we study in the NRSD (Levy et al. 2019), and another study finds that in 2016 30% of U.S. adult vaporers purchased e-cigarettes in retail stores (Braak et al. 2019). However, e-cigarette taxes are collected for both online and vape shop purchases in the same way they are collected in retail stores, so we are unaware of any financial incentive to change shopping venue in response to an e-cigarette tax.[29]

[29] In order to address the potential concern that transactions in the NRSD are not a nationally representative sample, we conduct a separate analysis using the NielsenIQ Consumer Panel Dataset. We regress the share of monthly e-cigarette purchases in a household (when not zero) occurring in one of several relevant retail channels, e.g. convenience stores, grocery stores, liquor stores, etc., on household demographics, weighting the regressions by projection factors designed to produce nationally representative estimates. We also do the same for online and

Moreover, e-cigarette taxes are found to operate similarly in studies using survey data on adult e-cigarette and cigarette use (Pesko, Courtemanche, and Maclean 2020), and administrative and survey data for pregnant women (Abouk et al. 2020), suggesting external validity.

7. Conclusion

Cigarettes continue to kill nearly 480,000 Americans each year (Centers for Disease Control and Prevention 2019a), and several reviews support the conclusion that e-cigarettes contain fewer toxicants (National Academies of Sciences Engineering and Medicine 2018, Royal College of Physicians 2019) and are safer for non-pregnant adults (Royal College of Physicians 2019) than cigarettes. Our results suggest that e-cigarettes are elastic goods and their use substantially reduces cigarette sales.

Despite potentially detrimental unintended consequences of e-cigarette taxes, between the end of our study period (December 2017) and December 2020, 20 additional states enacted e-cigarette taxes, bringing the total to 28 (Public Health Law Center 2020). As of September 30, 2020, 39 jurisdictions and three American Indian tribes have banned the sale of all e-cigarettes (Truth Initative 2020), which is analogous to an infinite e-cigarette price increase absent (likely) black market activity. Policymakers should consider unintended costs when setting e-cigarette policy.

remote purchase categories instead of retail channels. The adjusted R-squared does not exceed 10% in any regression, and in only one regression is it above 5% (grocery stores). These low R-squared values suggest that a small proportion of the variation in where e-cigarettes are purchased is explained by demographic characteristics, and this finding offers evidence that our main NRSD coefficient estimates are not substantially impacted by varying levels of data availability by retail channel.

References

Abouk, Rahi, Scott Adams, Bo Feng, Johanna Catherine Maclean, and Michael F Pesko. 2020. "The Effect of E-Cigarette Taxes on Pre-Pregnancy and Prenatal Smoking, and Birth Outcomes." *NBER Working Paper No. 26126*.

Agrawal, David R, and William H Hoyt. 2019. "Tax Incidence in a multi-product world: Theoretical foundations and empirical implications." *Working Paper*.

Allcott, Hunt, and Charlie Rafkin. 2020. "Optimal Regulation of E-cigarettes: Theory and Evidence." *NBER Working Paper No. 27000*.

Altonji, Joseph G, Todd E Elder, and Christopher R Taber. 2005. "Selection on observed and unobserved variables: Assessing the effectiveness of Catholic schools." *Journal of political economy* 113 (1):151-184.

Berry, William D, Evan J Ringquist, Richard C Fording, and Russell L Hanson. 1998. "Measuring citizen and government ideology in the American states, 1960-93." *American Journal of Political Science*:327-348.

Besley, Timothy. 1989. "Commodity taxation and imperfect competition: A note on the effects of entry." *Journal of Public Economics* 40 (3):359-367.

Besley, Timothy, and Anne Case. 2000. "Unnatural experiments? Estimating the incidence of endogenous policies." *The Economic Journal* 110 (467):672-694.

Besley, Timothy J, and Harvey S Rosen. 1999. "Sales Taxes and Prices: An Empirical Analysis." *National Tax Journal* 52:157-178.

Braak, David C, K Michael Cummings, Georges J Nahhas, Bryan W Heckman, Ron Borland, Geoffrey T Fong, David Hammond, Christian Boudreau, Ann McNeill, and David T Levy. 2019. "Where do vapers buy their vaping supplies? Findings from the international tobacco control (ITC) 4 country smoking and vaping survey." *International Journal of Environmental Research and Public Health* 16 (3):338.

Cawley, John, Anne Marie Thow, Katherine Wen, and David Frisvold. 2019. "The Economics of Taxes on Sugar-Sweetened Beverages: A Review of the Effects on Prices, Sales, Cross-Border Shopping, and Consumption." *Annual Review of Nutrition* 39:317-338.

Centers for Disease Control and Prevention. 2018. "Tobacco Product Use Among Adults — United States, 2017." *Morbidity and Mortality Weekly Report* 67 (44):1225-1232.

Centers for Disease Control and Prevention. 2019a. "Smoking & Tobacco Use Fast Facts." Last Modified Novebmer 15, 2019, accessed January 20, 2020. https://www.cdc.gov/tobacco/data_statistics/fact_sheets/fast_facts/index.htm.

Centers for Disease Control and Prevention. 2019b. State Tobacco Activities Tracking and Evaluation (STATE) System.

Chaloupka, Frank J, and Kenneth E Warner. 2000. "The economics of smoking." *Handbook of Health Economics* 1:1539-1627.

CNN. 2019. "The US and UK see vaping very differently. Here's why." Last Modified September 17, 2019, accessed 3/20/2020. https://www.cnn.com/2019/09/17/health/vaping-us-uk-e-cigarette-differences-intl/index.html.

Cotti, Chad, Erik Nesson, and Nathan Tefft. 2018. "The relationship between cigarettes and electronic cigarettes: Evidence from household panel data." *Journal of Health Economics* 61:205-219.

DeCicca, Philip, Donald Kenkel, and Feng Liu. 2013. "Who pays cigarette taxes? The impact of consumer price search." *Review of Economics and Statistics* 95 (2):516-529.

DeCicca, Philip, Donald S Kenkel, and Michael F Lovenheim. 2020. The Economics of Tobacco Regulation: A Comprehensive Review. National Bureau of Economic Research.

DeCicca, Philip, Donald S Kenkel, Michael F Lovenheim, and Erik Nesson. 2018. "The Economics of Smoking Prevention." In *Oxford Research Encyclopedia of Economics and Finance*.

Gehrsitz, Markus, Henry Saffer, and Michael Grossman. 2020. "The effect of changes in alcohol tax differentials on alcohol consumption." *NBER Working Paper No. 27117*.

Hajek, Peter, Anna Phillips-Waller, Dunja Przulj, Francesca Pesola, Katie Myers Smith, Natalie Bisal, Jinshuo Li, Steve Parrott, Peter Sasieni, and Lynne Dawkins. 2019. "A randomized trial of e-cigarettes versus nicotine-replacement therapy." *New England Journal of Medicine* 380 (7):629-637.

Hamilton, Stephen F. 1999. "Tax incidence under oligopoly: a comparison of policy approaches." *Journal of Public Economics* 71 (2):233-245.

Hanson, Andrew, and Ryan Sullivan. 2009. "The incidence of tobacco taxation: evidence from geographic micro-level data." *National Tax Journal* 62 (4):677-698.

Harding, Matthew, Ephraim Leibtag, and Michael F Lovenheim. 2012. "The heterogeneous geographic and socioeconomic incidence of cigarette taxes: evidence from Nielsen homescan data." *American Economic Journal: Economic Policy* 4 (4):169-98.

U.S. House of Representitives. 2020. *Protecting American Lungs and Reversing the Youth Tobacco Epidemic Act of 2020*. 116th Congress, 2339.

Kenkel, Donald S. 2005. "Are alcohol tax hikes fully passed through to prices? Evidence from Alaska." *American Economic Review* 95 (2):273-277.

Lester, Toby. 2020. "How Philip Morris Is Planning for a Smoke-Free Future." Havard Business Review, accessed 8/8/2020. https://hbr.org/2020/07/how-philip-morris-is-planning-for-a-smoke-free-future.

Levy, David T, Eric N Lindblom, David T Sweanor, Frank Chaloupka, Richard J O'connor, Ce Shang, Thomas Palley, Geoffrey T Fong, Michael K Cummings, and Maciej L Goniewicz. 2019. "An economic analysis of the Pre-Deeming us market for nicotine Vaping products." *Tobacco Regulatory Science* 5 (2):169-181.

Lillard, Dean R. 2020. "The Economics of Nicotine Consumption." In *Handbook of Labor, Human Resources and Population Economics*, 1-31. Springer.

Lillard, Dean R, and Andrew Sfekas. 2013. "Just passing through: the effect of the Master Settlement Agreement on estimated cigarette tax price pass-through." *Applied Economics Letters* 20 (4):353-357.

Maclean, Johanna Catherine, and Brendan Saloner. 2018. "Substance use treatment provider behavior and healthcare reform: Evidence from Massachusetts." *Health Economics* 27 (1):76-101.

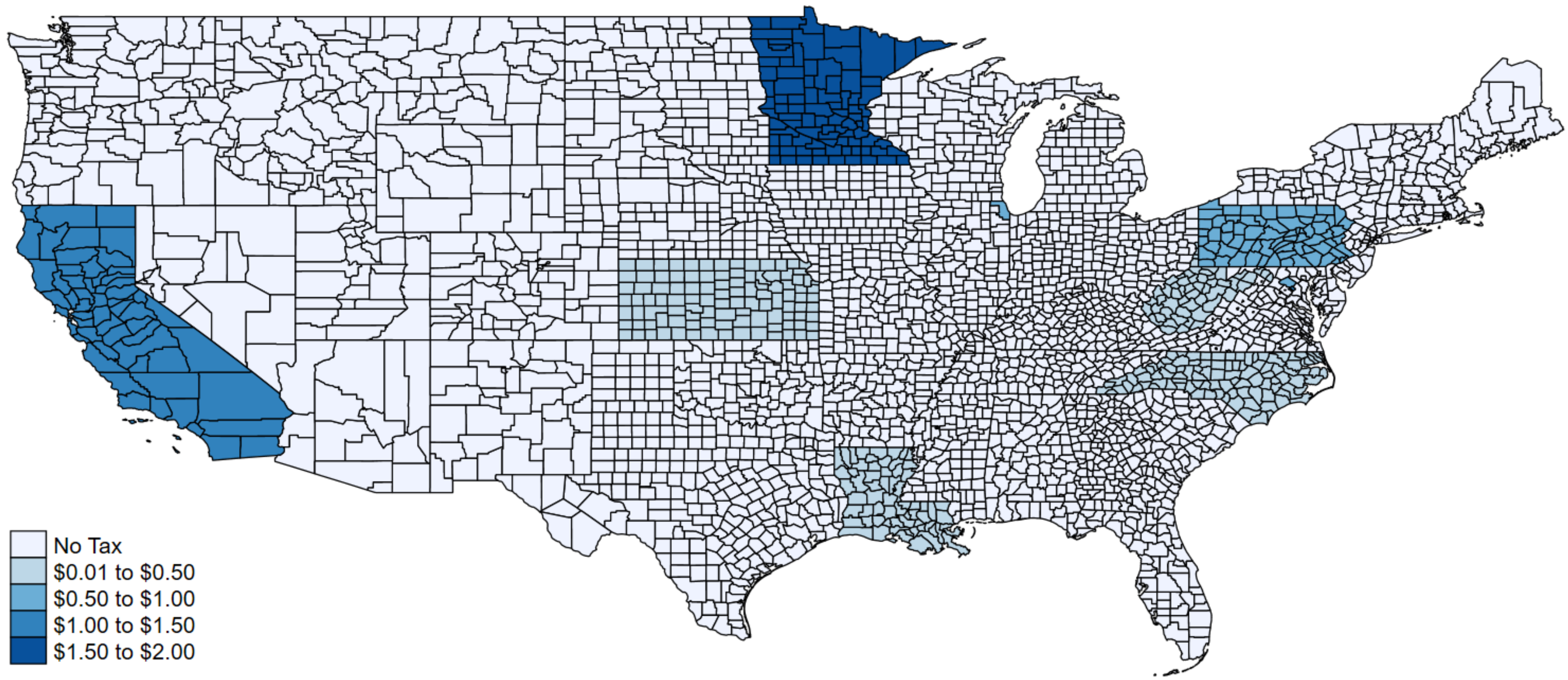
Meer, Jonathan, and Jeremy West. 2016. "Effects of the minimum wage on employment dynamics." *Journal of Human Resources* 51 (2):500-522.

Mullahy, John. 2021. "Inverse Hyperbolic Sine Transformations and Retransformations." *University of Wisconsin Working Paper*.

National Academies of Sciences Engineering and Medicine. 2018. *Public Health Consequences of E-Cigarettes*. Edited by Kathleen Stratton, Leslie Y. Kwan and David L. Eaton. Washington, DC: The National Academies Press.

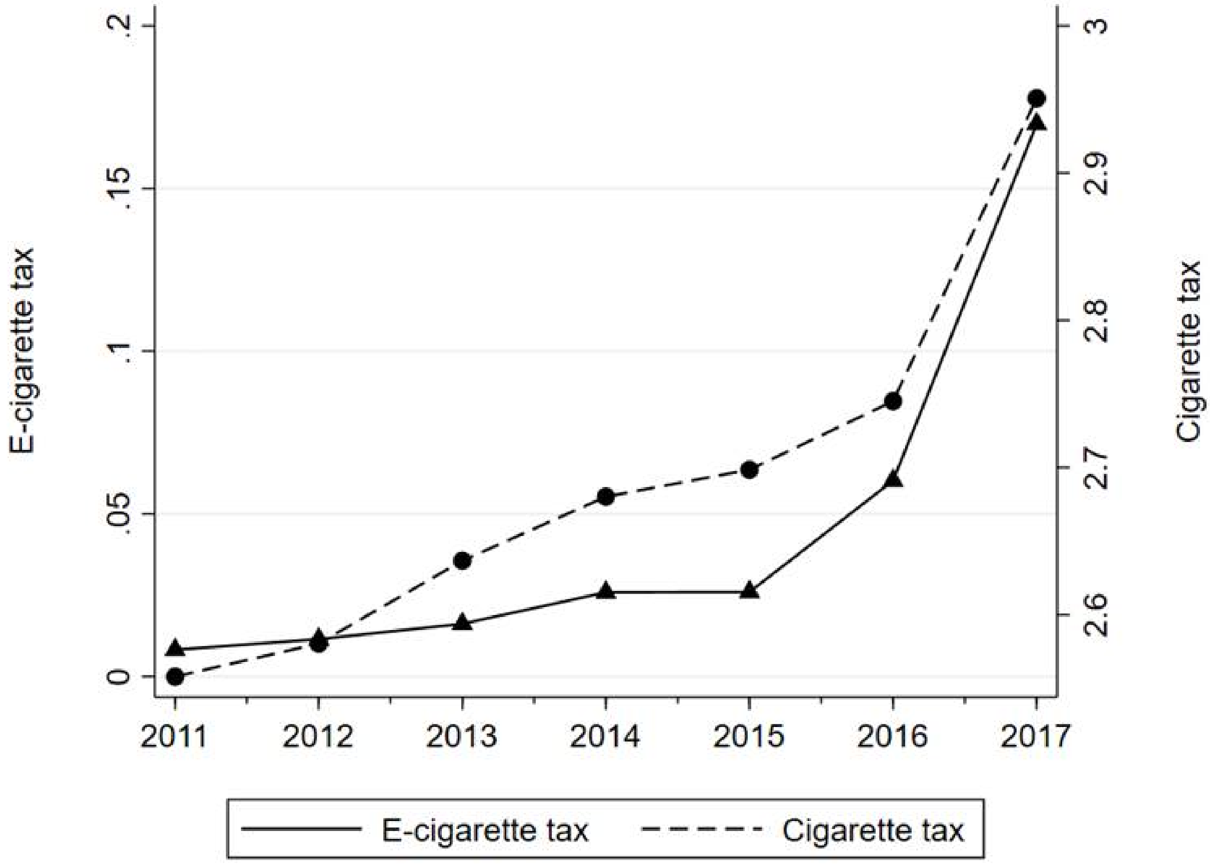
Pei, Zhuan, Jörn-Steffen Pischke, and Hannes Schwandt. 2019. "Poorly measured confounders are more useful on the left than on the right." *Journal of Business & Economic Statistics* 37 (2):205-216.
Pesko, Michael F, Charles J Courtemanche, and Johanna Catherine Maclean. 2020. "The Effects of Traditional Cigarette and E-Cigarette Taxes on Adult Tobacco Product Use." *Journal of Risk & Uncertainty* 30 (3).
Public Health Law Center. 2020. States & Territories with Laws Taxing E-Cigarettes Enacted as of December 15, 2020. Public Health Law Center at the Mitchell Hamline School of Law.
Robinson, Peter M. 1988. "Root-N-consistent semiparametric regression." *Econometrica* 56 (4):931-954.
Rodu, Brad, and Nantaporn Plurphanswat. 2017. "Quit methods used by American smokers, 2013–2014." *International Journal of Environmental Research and Public Health* 14 (11):1403.
Royal College of Physicians. 2019. Promote e-cigarettes widely as substitute for smoking says new RCP report.
Rozema, Kyle, and Nicolas R Ziebarth. 2017. "Taxing consumption and the take-up of public assistance: The case of cigarette taxes and food stamps." *The Journal of Law and Economics* 60 (1):1-27.
Saffer, Henry, Daniel L Dench, Michael Grossman, and Dhaval M Dave. 2020. "E-Cigarettes and Adult Smoking: Evidence from Minnesota." *Journal of Risk & Uncertainty* 30 (3).
Sandler, Danielle H, and Ryan Sandler. 2014. "Multiple event studies in public finance and labor economics: A simulation study with applications." *Journal of Economic and Social Measurement* 39 (1-2):31-57.
Shang, Ce, Anh Ngo, and Frank J Chaloupka. 2020. "The pass-through of alcohol excise taxes to prices in OECD countries." *The European Journal of Health Economics*:1-13.
Shrestha, Vinish, and Sara Markowitz. 2016. "The Pass-Through of Beer Taxes to Prices: Evidence from State and Federal Tax Changes." *Economic Inquiry* 54 (4):1946-1962.
Soneji, Samir S, Kristin E Knutzen, and Andrea C Villanti. 2019. "Use of flavored e-cigarettes among adolescents, young adults, and older adults: findings from the population assessment for tobacco and health study." *Public Health Reports* 134 (3):282-292.
Stern, Nicholas. 1987. "The effects of taxation, price control and government contracts in oligopoly and monopolistic competition." *Journal of Public Economics* 32 (2):133-158.
Tax Data Center. 2019. Vapor Products Tax Database.
Truth Initative. 2020. Local flavored tobacco policies as of September 30, 2020.
U.S. Department of Justice. 2010. "Horizontal Merger Guidelines." Last Modified July 31, 2018, accessed January 18, 2020. https://www.justice.gov/atr/horizontal-merger-guidelines-08192010.
U.S. Food & Drug Administration. 2019. Trump Administration Combating Epidemic of Youth E-Cigarette Use with Plan to Clear Market of Unauthorized, Non-Tobacco-Flavored E-Cigarette Products.
University of Kentucky Center for Poverty Research. 2021. UKCPR National Welfare Data, 1980-2019. Lexington, KY.

Figure 1. Map of e-cigarette taxes per ml of vaping liquid in quarter four 2017



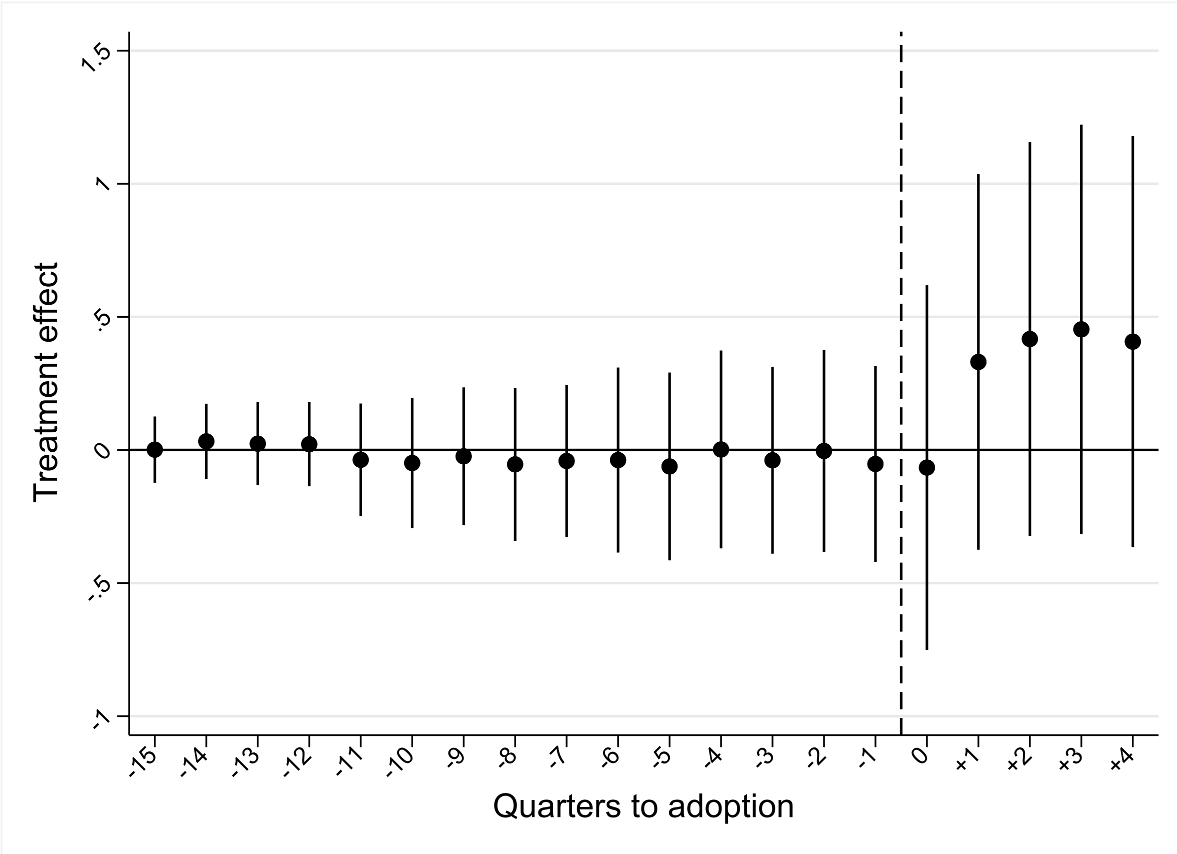
Notes: See text for details.

Figure 2. Comparison of e-cigarette and cigarette tax levels



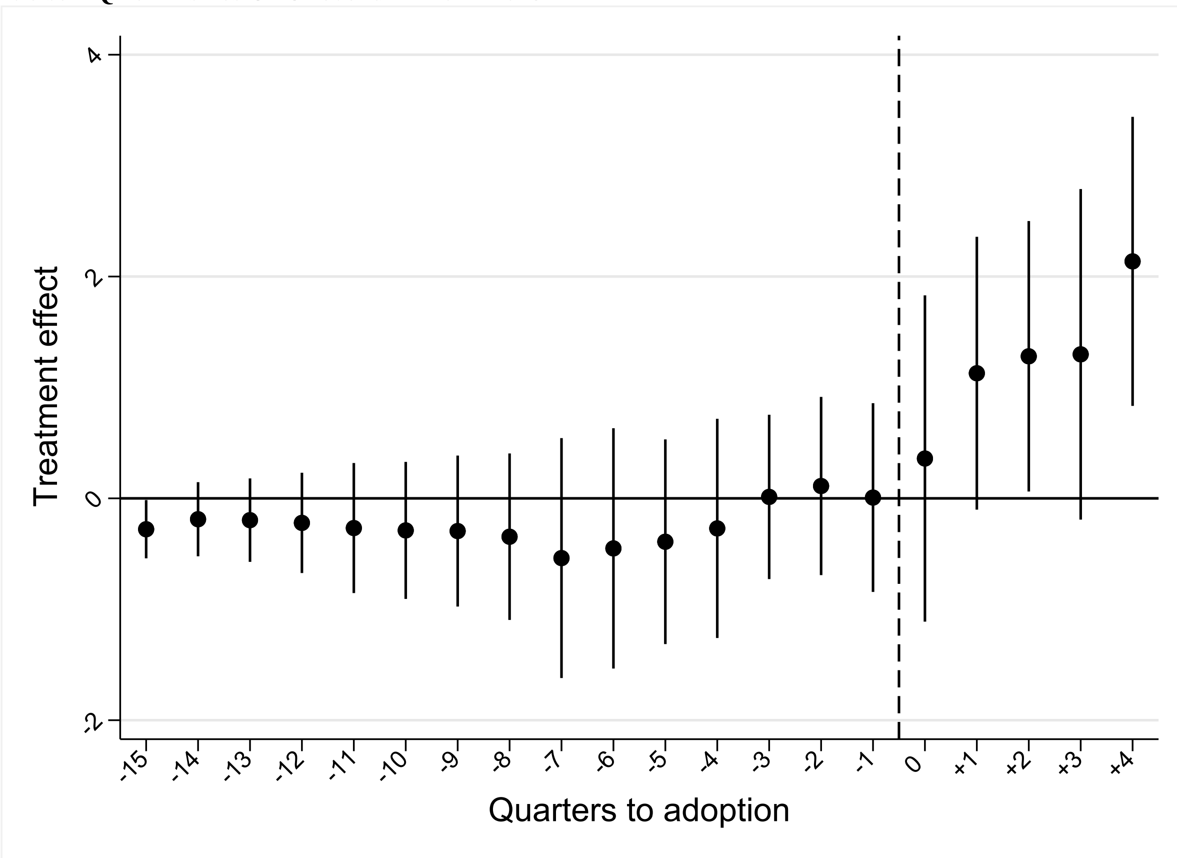
Notes: See text for details. E-cigarette tax is in dollars per fluid mL and cigarette taxes is in dollars per pack.

Figure 3. Effect of e-cigarette taxes on e-cigarette prices using an event study: NielsenIQ retail sales UPC-level data 2011-2017



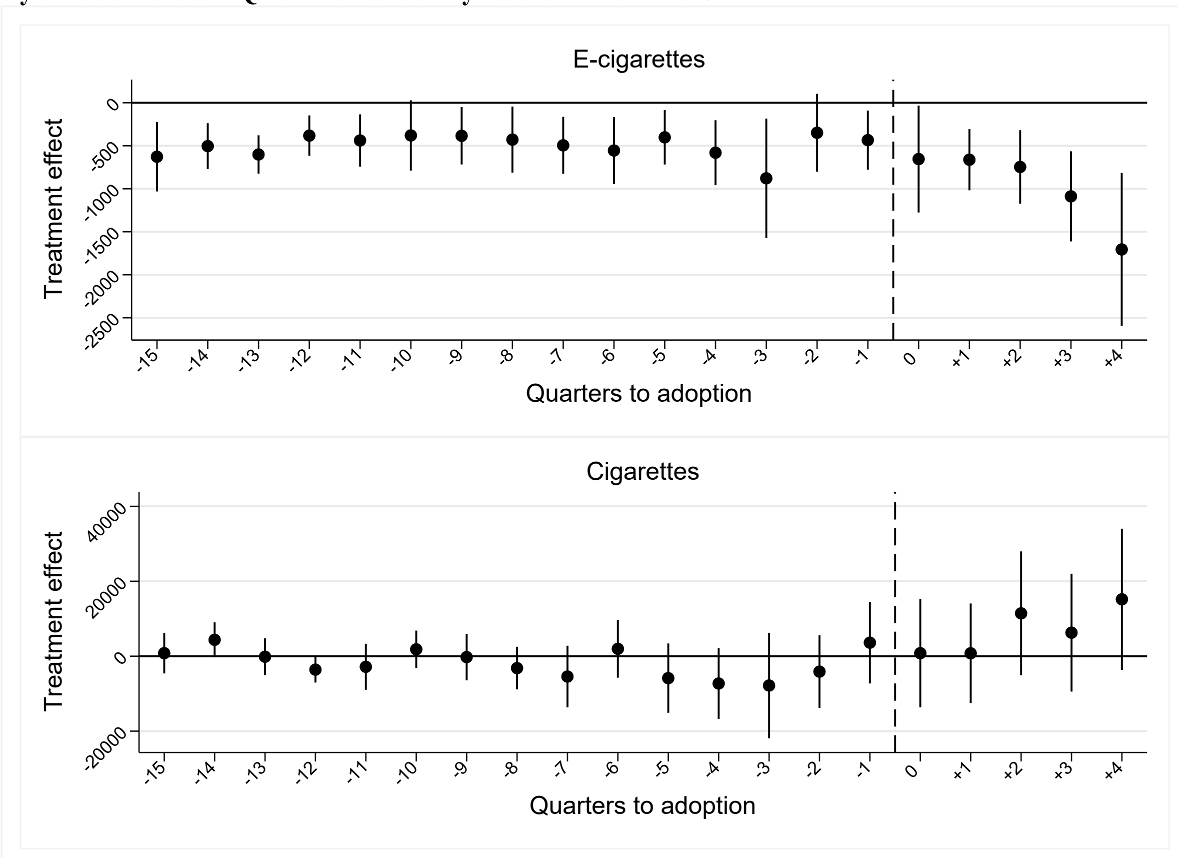
Notes: The unit of observation is a UPC-code in a locality (state or county) in a quarter (quarter-by-year). The model is estimated by equation (1) except using lag and lead indicators from the first available e-cigarette tax in a given locality. The model is estimated with least squares and controls for time-varying locality characteristics, UPC-by-locality fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the share of e-cigarette sales in localities that do not adopt an e-cigarette tax. Circles reflect the coefficient estimate and vertical solid lines reflect 95% confidence intervals. The omitted category is ≥16 quarters prior to policy adoption, this category is normalized to zero.

Figure 4. Effect of e-cigarette taxes on e-cigarette prices using a Cotti et al (2018) event study-style model: NielsenIQ retail sales UPC-level data 2011-2017



Notes: The unit of observation is a UPC-code in a locality (state or county) in a quarter (quarter-by-year). The model is estimated by equation (1) except using lag and lead changes in the e-cigarette tax amount. The model is estimated with least squares and controls for time-varying locality characteristics, UPC-by-locality fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the share of e-cigarette sales in localities that do not adopt an e-cigarette tax. Circles reflect the coefficient estimate and vertical solid lines reflect 95% confidence intervals. The omitted category is the e-cigarette tax change ≥16 quarters prior to policy adoption, this category is normalized to zero.

Figure 5. Effect of e-cigarette taxes on e-cigarette and cigarette sales using a Cotti et al (2018) event study-style model: NielsenIQ retail sales locality-level data 2011-2017



Notes: The unit of observation is a locality (state or county) in a quarter (quarter-by-year). The model is estimated by equation (3) except using lag and lead changes in the e-cigarette tax amount. The model is estimated with least squares and controls for time-varying locality characteristics, locality fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the locality population. Circles reflect the beta coefficient estimate and vertical solid lines reflect 95% confidence intervals. The omitted category is the e-cigarette tax change ≥16 quarters prior to policy adoption, this category is normalized to zero.

Table 1. Summary statistics: NielsenIQ retail sales UPC-level data 2011-2017

Sample:	**All localities**	**Localities that adopt a tax by 2017, pre-tax**	**Localities that do not adopt a tax by 2017**
Prices			
E-cigarette ($ per ml)	4.35	4.46	4.29
	(3.09)	(3.06)	(3.01)
E-cigarette and cigarette taxes			
E-cigarette standardized tax ($)	0.04	--	--
	(0.22)	--	--
Conditional e-cigarette standardized tax ($)	0.67	--	--
	(0.56)	--	--
Conditional e-cigarette standardized tax ($) – unit	0.21	--	--
	(0.29)	--	--
Conditional e-cigarette standardized tax ($) – ad valorem	1.02	--	--
	(0.45)	--	--
Cigarette tax ($)	2.69	2.55	2.67
	(1.16)	(1.37)	(1.10)
Observations	91299	9763	74168

Notes: The unit of observation is a UPC-code in a locality (state or county) in a quarter (quarter-by-year). Data are weighted by the share of e-cigarette sales in localities that do not adopt an e-cigarette tax. Values in parentheses are standard deviations for continuous variables.

Table 2. Summary statistics: NielsenIQ retail sales locality-level data 2011-2017

Sample:	All localities	Localities that adopt a tax by 2017, pre-tax	Localities that do not adopt a tax by 2017
Sales per 100,000 locality adult residents			
E-cigarette (ml)	1,388	914	1,520
	(886)	(625)	(921)
Cigarette (packs)	80,752	59,356	88,536
	(59,125)	(38,271)	(63,336)
Non-flavored e-cigarettes (ml)	601	418	661
	(426)	(295)	(453)
Menthol e-cigarettes (ml)	370	258	406
	(268)	(210)	(279)
Flavored e-cigarettes (ml)	416	237	450
	(368)	(194)	(389)
Non-flavored cigarettes (packs)	59,840	42,860	65,880
	(47,021)	(26,367)	(51,168)
Menthol cigarettes (packs)	20,912	16,496	22,656
	(13,220)	(12,633)	(13,176)
Cigar (units)	5,586	3,362	6,141
	(4,100)	(3,102)	(3,992)
Chewing tobacco (ounces)	5,619	5,166	5,626
	(7,830)	(10,819)	(6,485)
Loose tobacco (ounces)	714	593	726
	(702)	(441)	(729)
Refill e-cigarettes (ml)	878	537	963
	(676)	(394)	(714)
Disposable e-cigarettes (ml)	345	205	397
	(327)	(175)	(354)
Starter kits for e-cigarettes (kits)	70	55	77
	(79)	(62)	(84)
E-cigarette and cigarette prices			
E-cigarette price ($)	4.42	4.49	4.35
	(0.97)	(0.93)	(0.91)
Cigarette price ($)	6.20	5.73	6.25
	(1.56)	(1.21)	(1.59)
E-cigarette and cigarette taxes			
E-cigarette tax ($)	0.05	--	--
	(0.23)	--	--
Conditional e-cigarette tax ($)	0.71	--	--
	(0.56)	--	--
Conditional e-cigarette tax ($) - unit	0.19	--	--
	(0.29)	--	--
Conditional e-cigarette tax ($) - ad valorem	1.03	--	--
	(0.43)	--	--
Cigarette tax ($)	2.79	2.31	2.88
	(1.30)	(1.07)	(1.31)
Policies and demographics			
% covered by indoor vaping ban	0.14	0.14	0.12
	(0.27)	(0.26)	(0.24)
% covered by indoor smoking ban	0.69	0.73	0.66
	(0.33)	(0.17)	(0.36)
Share of border localities without an e-cigarette tax	0.95	1.00	0.94
	(0.12)	(0.01)	(0.13)
Vape-free public K-12 schools	0.10	0.02	0.11

Smoke-free public K-12 schools	0.31	0.20	0.33
Tobacco 21 law	0.03	0.07	0
Beer tax ($)	0.29	0.24	0.31
	(0.26)	(0.15)	(0.28)
Affordable Care Act Medicaid expansion	0.34	0.38	0.30
Unemployment rate	6.45	7.73	6.24
	(1.95)	(2.04)	(1.83)
Age	38.2	37.6	38.3
	(1.63)	(1.25)	(1.73)
Male	0.49	0.49	0.49
	(0.01)	(0.01)	(0.01)
Female	0.51	0.51	0.51
	(0.01)	(0.01)	(0.01)
White	0.78	0.76	0.79
	(0.08)	(0.07)	(0.08)
African American	0.13	0.11	0.13
	(0.00)	(0.08)	(0.08)
Other race	0.09	0.13	0.08
	(0.05)	(0.07)	(0.04)
Hispanic	0.17	0.25	0.16
	(0.13)	(0.15)	(0.12)
Born outside the U.S.	0.14	0.19	0.13
	(0.08)	(0.10)	(0.07)
Less than high school	0.16	0.18	0.16
	(0.03)	(0.03)	(0.03)
High school	0.28	0.27	0.29
	(0.04)	(0.06)	(0.03)
Some college	0.27	0.27	0.27
	(0.03)	(0.02)	(0.03)
College	0.28	0.28	0.28
	(0.05)	(0.04)	(0.05)
Population (millions)	14.0	25.0	11.0
	(11.6)	(15.3)	(8.00)
Observations	1428	185	1148

Notes: The unit of observation is a locality (state or county) in a period (quarter-by-year). Data are weighted by the locality population. Values in parentheses are standard deviations for continuous variables.

Table 3. Effect of e-cigarette and cigarette taxes on e-cigarette prices using a two-way fixed effects model: NielsenIQ retail sales UPC-level data 2011-2017

Outcome:	**E-cigarette price ($)**			
E-cigarette tax ($)	1.236***	1.515***	1.579***	1.436***
	(0.141)	(0.162)	(0.192)	(0.142)
Cigarette tax ($)	0.013	-0.004	-0.036	0.086
	(0.013)	(0.103)	(0.087)	(0.108)
Locality fixed effects	N	Y	Y	n/a
Period (quarter-by-year) fixed effects	N	Y	Y	Y
Time-varying controls	N	N	Y	Y
UPC-by-locality fixed effects	N	N	N	Y
Observations	91299	91299	91299	91299
Mean: E-cigarette price in e-cigarette tax adopting localities, year prior to the tax ($)	3.666	3.666	3.666	3.666

Notes: The unit of observation is a UPC-code in a locality (state or county) in a quarter (quarter-by-year). All models estimated with least squares. Data are weighted by the share of e-cigarette sales in localities that do not adopt an e-cigarette tax. Standard errors that account for within-locality clustering are reported in parentheses. ***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

Table 4A. Effect of e-cigarette taxes on e-cigarette prices using a two-way fixed effects model, alternative samples: NielsenIQ retail sales UPC-level data 2011-2017

Outcome:	**E-cigarette price ($)**
Mean: E-cigarette tax adopting localities, year prior to the tax ($)†	3.666
Exclude divisions with no adopting localities by 2017 (New England, East South Central, and Mountain)	
E-cigarette tax ($)	1.380***
	(0.111)
Observations	59622
Impute missing e-cigarette prices††	
E-cigarette tax ($)	1.385***
	(0.113)
Observations	113709
Drop enactment period	
E-cigarette tax ($)	1.532***
	(0.160)
Observations	89441
Drop 2011-2012	
E-cigarette tax ($)	1.245***
	(0.141)
Observations	83576
Drop treated state localities	
E-cigarette tax ($)	1.427***
	(0.138)
Observations	87669
Drop treated sub-state localities	
E-cigarette tax ($)	1.652***
	(0.087)
Observations	88448
Use excise tax localities only (exclude localities with ad valorem taxes)	
E-cigarette tax ($)	0.856***
	(0.023)
Observations	83147
Use ad valorem tax localities only (standardized in dollars; exclude localities with excise taxes)	
E-cigarette tax ($)	1.576***
	(0.099)
Observations	82320
Use ad valorem tax localities only (tax in natural units; exclude localities with excise taxes)	
E-cigarette tax (percentage point)	0.030***
	(0.003)
Observations	82320
Drop border counties	
E-cigarette tax ($)	1.564***
	(0.191)
Observations	84723

Notes: The unit of observation is a UPC-code in a locality (state or county) in a quarter (quarter-by-year). All models estimated with least squares and control for time-varying locality characteristics, UPC-by-locality fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the share of e-cigarette sales in localities that do not adopt an e-cigarette tax. Standard errors that account for within-locality clustering are reported in parentheses.

†Based on the full sample.

††For localities with zero sales for a given UPC code (and hence no available prices), we forward impute with the

last available price if a sale had previously been made for that UPC in that locality.
***, **, and * = statistically different from zero at the 1%, 5%, and 10% level.

Table 4B. Effect of e-cigarette taxes on e-cigarette prices using a two-way fixed effects model, alternative specifications: NielsenIQ retail sales UPC-level data 2011-2017

Outcome:	**E-cigarette price ($)**
Mean: E-cigarette tax adopting localities, year prior to the tax ($)	3.666
Include division-by-quarter fixed effects	
E-cigarette tax ($)	1.443***
	(0.129)
Include UPC-by-quarter fixed effects	
E-cigarette tax ($)	1.550***
	(0.234)
Unweighted	
E-cigarette tax ($)	1.369***
	(0.212)
Weight by population	
E-cigarette tax ($)	1.375***
	(0.196)
Weight by quarterly e-cigarette sales in 2013	
E-cigarette tax ($)	1.199***
	(0.236)
Use alternative e-cigarette tax variable†	
E-cigarette tax ($)	1.187***
	(0.247)
Control for the enactment period	
E-cigarette tax ($)	1.423***
	(0.149)
Lag e-cigarette tax one quarter	
E-cigarette tax ($)	1.524***
	(0.131)
Lag e-cigarette tax one year	
E-cigarette tax ($)	1.466***
	(0.330)
Control for political variables	
E-cigarette tax ($)	1.436***
	(0.140)
Observations	91299
Use e-cigarette tax variable using only refills††	
E-cigarette tax ($)	1.223***
	(0.276)
Observations	50,600

Notes: The unit of observation is a UPC-code in a locality (state or county) in a quarter (quarter-by-year). All models estimated with least squares and control for time-varying locality characteristics, UPC-by-locality fixed effects, and period (quarter-by-year) fixed effects unless otherwise noted. Data are weighted by the share of e-cigarette sales in localities that do not adopt an e-cigarette tax unless otherwise noted. Standard errors that account for within-locality clustering are reported in parentheses.

† Using market information specific to each locality, rather than across non-adopting localities. See the appendix for additional details.

†† A wholesale price estimate for refills of $3.52 is used in the standardization, as explained in the appendix.

***, **, and * = statistically different from zero at the 1%, 5%, and 10% level.

Table 5A. Effect of e-cigarette and cigarette taxes on e-cigarette sales per 100,000 state adult residents using a two-way fixed effects model: NielsenIQ retail sales locality-level data 2011-2017

Outcome:		**E-cigarettes**	
E-cigarette tax ($)	-394	-631**	-756***
	(242)	(254)	(208)
Cigarette tax ($)	86	387***	371***
	(67)	(123)	(82)
Locality fixed effects	N	Y	Y
Period (quarter-by-year) fixed effects	N	Y	Y
Time-varying controls	N	N	Y
Observations	1428	1428	1428
Mean: E-cigarette tax adopting localities, year prior to the tax	1,307	1,307	1,307
Mean: Cigarette tax adopting localities, year prior to the first cigarette tax increase	1,194	1,194	1,194

Notes: The unit of observation is a locality (state or county) in a quarter (quarter-by-year). All models estimated with least squares and control for time-varying locality characteristics, locality fixed effects, and period (quarter-by-year) fixed effects unless otherwise noted. Data are weighted by the locality population. Standard errors that account for within-locality clustering are reported in parentheses.
***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

Table 5B. Effect of e-cigarette and cigarette taxes on cigarette sales per 100,000 state adult residents using a two-way fixed effects model: NielsenIQ retail sales locality-level data 2011-2017

Outcome:		**Cigarettes**	
E-cigarette tax ($)	-28,255***	16,091***	11,329**
	(5,187)	(5,247)	(4,568)
Cigarette tax ($)	-10,436***	-5,175	-6,970**
	(3,602)	(3,662)	(3,009)
Locality fixed effects	N	Y	Y
Period (quarter-by-year) fixed effects	N	Y	Y
Time-varying controls	N	N	Y
Observations	1428	1428	1428
Mean: E-cigarette tax adopting localities, year prior to the tax	56,470	56,470	56,470
Mean: Cigarette tax adopting localities, year prior to the first cigarette tax increase	70,079	70,079	70,079

Notes: The unit of observation is a locality (state or county) in a quarter (quarter-by-year). All models estimated with least squares and control for time-varying locality characteristics, locality fixed effects, and period (quarter-by-year) fixed effects unless otherwise noted. Data are weighted by the locality population. Standard errors that account for within-locality clustering are reported in parentheses.
***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

Table 6A. Effect of e-cigarette and cigarette taxes on flavored e-cigarettes and cigarettes sales per 100,000 adults using a two-way fixed effects model: NielsenIQ state-level sales data 2011-2017

Cigarette type:	**E-cigarettes**			**Cigarettes**	
Outcome:	**Non-flavored**	**Menthol /mint**	**Flavored**	**Non-flavored**	**Menthol**
E-cigarette tax ($)	-328***	-201***	-204**	7,702**	3,800**
	(105)	(75)	(83)	(3,422)	(1,461)
Cigarette tax ($)	142***	85**	120***	-4,131*	-3,022***
	(51)	(40)	(35)	(2,318)	(825)
Observations	1428	1428	1428	1428	1428
Mean: E-cigarette tax adopting localities, year prior to the tax	491	317	496	41,967	14,503
Mean: Cigarette tax adopting localities, year prior to the first cigarette tax increase	515	321	356	50,996	19,083

Notes: The unit of observation is a locality (state or county) in a quarter (quarter-by-year). All models estimated with least squares and control for time-varying area characteristics, area fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the locality population. Standard errors that account for within-locality clustering are reported in parentheses.
***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

Table 6B. Effect of e-cigarette and cigarette taxes on other tobacco product sales per 100,000 adults using a two-way fixed effects model: NielsenIQ state-level sales data 2011-2017

Tobacco product:	**Cigars**	**Chewing tobacco**	**Loose tobacco**
E-cigarette tax ($)	-481	-10	-148
	(596)	(747)	(146)
Cigarette tax ($)	98	-120	13
	(405)	(362)	(93)
Observations	1428	1428	1428
Mean: E-cigarette tax adopting localities, year prior to the tax	4,382	5,448	557
Mean: Cigarette tax adopting localities, year prior to the first cigarette tax increase	3,961	2,722	580

Notes: The unit of observation is a locality (state or county) in a quarter (quarter-by-year). All models estimated with least squares and control for time-varying area characteristics, area fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the locality population. Standard errors that account for within-locality clustering are reported in parentheses.
***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

Table 7. Effect of e-cigarette and cigarette taxes on the prices, number of new e-cigarette products, and liquid per unit using a two-way fixed effects model: NielsenIQ retail sales state-level data 2011-2017

Outcome:	**Number of new e-cigarette products**	**Liquid per unit (ml)**	**Nicotine % of liquid amount**
E-cigarette tax ($)	-2.574	-0.290	0.174**
	(1.795)	(0.187)	(0.081)
Cigarette tax ($)	-0.301	0.321**	-0.011
	(0.859)	(0.138)	(0.056)
Observations	1428	1428	1428
Mean: E-cigarette tax adopting localities, year prior to the tax	18.820	2.858	2.720
Mean: Cigarette tax adopting localities, year prior to the first cigarette tax increase	17.477	2.705	2.468

Notes: The unit of observation is a locality (state or county) in a quarter (quarter/year). All models estimated with least squares and control for time-varying locality characteristics, locality fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the locality population. Standard errors that account for within-locality clustering are reported in parentheses.
***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

Table 8. Effect of e-cigarette and cigarette prices on sales per 100,000 adults simultaneously instrumenting e-cigarette and cigarette prices with e-cigarette and cigarette taxes: NielsenIQ state-level sales data 2011-2017

Outcome:	**E-cigarettes**	**Cigarettes**
All states (e-cigarette tax rate standardized)		
E-cigarette price ($)	-378***	5,707**
	(104)	(2,251)
Cigarette price ($)	233**	-4,820*
	(91)	(2,492)
Observations	1428	1428
Exclude ad valorem localities		
E-cigarette price ($)	-996***	9,148*
	(296)	(4,859)
Cigarette price ($)	-211	-2,703
	(137)	(5,526)
Observations	1288	1288
Exclude excise localities (standardized tax)		
E-cigarette price ($)	-445***	7,839**
	(147)	(3,215)
Cigarette price ($)	325***	-6,915***
	(89)	(2,540)
Observations	1288	1288
Exclude excise localities (tax in natural units)		
E-cigarette price ($)	-516**	8,519**
	(219)	(3,957)
Cigarette price ($)	368***	-7,326***
	(92)	(2,782)
Observations	1288	1288
Mean: E-cigarette tax adopting localities, year prior to the tax†	1,307	56,470
Mean: Cigarette tax adopting localities, year prior to the first cigarette tax increase†	1,208	71,042

Notes: The unit of observation is a locality (state or county) in a quarter (quarter-by-year). All models estimated with two-stage least squares and control for time-varying area characteristics, area fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the locality population. 1st stage *F*-statistics are 80.70, 12.58, 41.63, and 19.67 for e-cigarette prices and 661.83, 680.75, 278.87, and 252.51 for cigarette prices in the full sample (panel A), sample that excludes ad valorem localities (panel B), sample that excludes excise localities and uses the standardized tax (panel C), and sample that excludes excise localities and uses the standardized tax (panel D). Standard errors that account for within-locality clustering are reported in parentheses.
***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.
†Based on the full sample.

Table 9. Effect of e-cigarette and cigarette prices on flavored tobacco product sales per 100,000 adults simultaneously instrumenting e-cigarette and cigarette prices with e-cigarette and cigarette taxes: NielsenIQ state-level sales data 2011-2017

Cigarette type:	**E-cigarettes**			**Cigarettes**	
Outcome:	**Non-flavored**	**Menthol /mint**	**Flavored**	**Non-flavored**	**Menthol**
E-cigarette price ($)	-172***	-106***	-99**	3,709**	1,998***
	(50)	(33)	(43)	(1,715)	(684)
Cigarette price ($)	98**	59**	76*	-2,466	-2,354***
	(47)	(27)	(43)	(1,908)	(688)
Observations	1428	1428	1428	1428	1428
Mean: E-cigarette tax adopting localities, year prior to the tax	491	317	496	41,967	14,503
Mean: Cigarette tax adopting localities, year prior to the first cigarette tax increase	515	321	356	50,996	19,083

Notes: The unit of observation is a locality (state or county) in a quarter (quarter-by-year). All models estimated with two-stage least squares and control for time-varying area characteristics, area fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the locality population. 1st stage *F*-statistics are 80.70 for e-cigarette prices and 661.83 for cigarette prices. Standard errors that account for within-locality clustering are reported in parentheses.

***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

Table 10. Effect of e-cigarette and cigarette prices on cigar, chewing tobacco, and loose tobacco sales per 100,000 adults simultaneously instrumenting e-cigarette and cigarette prices with e-cigarette and cigarette taxes: NielsenIQ state-level sales data 2011-2017

Tobacco product:	**Cigars**	**Chewing tobacco**	**Loose tobacco**
E-cigarette price ($)	-259	66	-76
	(298)	(346)	(67)
Cigarette tax ($)	58	-222	-3
	(323)	(266)	(76)
Observations	1428	1428	1428
Mean: E-cigarette tax adopting localities, year prior to the tax	4,382	5,448	557
Mean: Cigarette tax adopting localities, year prior to the first cigarette tax increase	3,961	2,722	580

Notes: The unit of observation is a locality (state or county) in a quarter (quarter-by-year). All models estimated with two-stage least squares and control for time-varying area characteristics, area fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the locality population. 1st stage F-statistics are 80.70 for e-cigarette prices and 661.83 for cigarette prices. Standard errors that account for within-locality clustering are reported in parentheses.
***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

Data Appendix

E-cigarette Tax Standardization Algorithm

E-cigarette taxes through 2017 are most commonly levied using either specific unit taxes or ad valorem taxes. Thus, in their natural units there is no obvious way to compare the taxes in terms of their magnitudes. We propose an algorithm that taxes advantage of equivalencies offered by two localities (California and Washington DC). We next describe our algorithm.

To standardize e-cigarette taxes levied in different ways into a single measure, we combine policy data on e-cigarette taxes with the NielsenIQ Retail Scanner data in order to convert ad valorem taxes into excise taxes measures (see Online Appendix Table 1 for a description of the taxes).[30]

Formally, we standardize e-cigarette ad valorem taxes into a unit tax equivalency (per ml of fluid) using the following formula:

$$(4)\ (Wholesale\ Price * ad\ valorem\ tax\ rate_{st}) * \frac{sales\ volume\ in\ retail\ units_{st}}{sales\ volume\ in\ ml\ of\ fluid_{st}} = tax\ per\ ml\ of\ fluid_{st}$$

Where s indexes a tax jurisdiction on a year-by-quarter basis t. Tax jurisdictions are defined for the purposes of our standardization algorithm as the state, except for Illinois and Maryland that have sub-state tax variation in which case the tax jurisdiction is either the sub-state (i.e., Chicago, Cook County, and Montgomery County) or the rest of the state.

Step 1: As shown in equation (4) above, the standardization process requires a measure of e-cigarette wholesale price for ad valorem tax localities. In Washington DC and California, the tax authorities determine the average wholesale price for a basket of all e-cigarette products sold in the locality and set the percent ad valorem tax to make the tax collection on the average e-cigarette product equivalent to the tax collection on a pack of cigarettes.[31] For example, from the 4th quarter of 2016 to the 3rd quarter of 2017, Washington DC's e-cigarette ad valorem tax rate was 65% and the cigarette tax rate was \$2.92, suggesting a wholesale price over this time period of \$4.49 (= \$2.92 / 0.65). Hence, by applying this algorithm to all quarters with e-cigarette taxes in California and Washington DC through the end of 2017, we derive an average wholesale price of \$4.35, which we use as a proxy wholesale price in equation (1) above. By taking the product of the wholesale price and the ad valorem tax rate we arrive at a measure of the typical amount of tax per e-cigarette product sold in each year-by-quarter period in each ad valorem taxing locality.

Step 2: Before we can convert the tax per unit measure into a tax per fluid ml, we require a measure of the retail units sold per fluid ml in each location and in each time period. We calculate this measure by dividing the total sales volume in retail units by total sales volume in ml of fluid for each tax jurisdiction s on a year-by-quarter basis t. Sales units include all disposable e-cigarettes, starter kits, and replacement cartridges in the NielsenIQ data that contain nicotine, after omitting

[30] Alaska and Hawaii are not included in NielsenIQ Retail Scanner data until 2018 and therefore are not included in this standardization exercise.
[31] Maine implemented a new e-cigarette tax in 2020 that also meets this criterion.

products for which fluid amounts or container amounts could not be identified using internet search and visits to retailers.[32]

Step 3: We use the ratio of units sold per fluid ml sold (calculated in Step 2) and multiply it by the tax per e-cigarette product sold (calculated in Step 1) for each ad valorem tax jurisdiction s for each time period t (quarter-year). This step provides us with an estimate of the unit tax per fluid ml for each jurisdiction using an ad valorem tax over time, and is now consistent with the excise taxes measures used by other treated localities.[33]

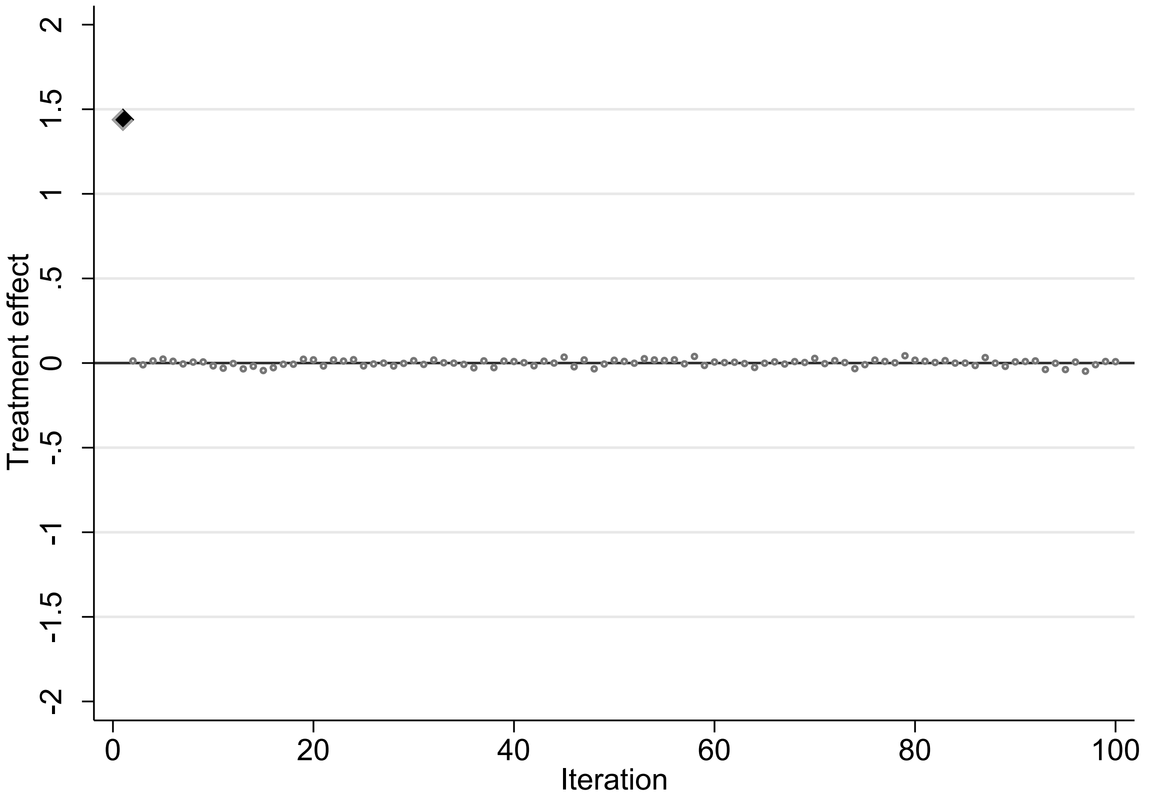
The overall accuracy of the standardization process of ad valorem taxes into per unit taxes is dependent on how representative the wholesale prices in Washington D.C. and California are for the other localities using ad valorem e-cigarette taxes in our analytical sample. We test the sensitivity of our estimates in the paper to this assumption using two approaches: 1) using a wholesale price estimate specifically for refills of $3.52 (Saffer et al. (2020), and 2) re-estimating the models separately for excise tax states and ad valorem states, using the unconverted tax rates that are not standardized. As outlined in the paper, our results are robust. The robustness of our results to these alternative approaches suggests that any difference in coefficient estimates between ad valorem and excise tax localities is most likely resulting from differences in the magnitudes of the taxes or the locations themselves, and not caused by any differences between the derived wholesale proxy we use in equation (4) and the actual (but unknown to researchers) wholesale price for each ad valorem locality.

Another potential concern with equation (1) is that the ratios of sales volumes in units (or containers) to sales volume in ml of fluid may be endogenous to the e-cigarette tax adoption. Our primary standardized tax measure uses the ratio for all locations that have not adopted e-cigarette taxes by January 2021. A ratio specific to each tax jurisdiction is also used in a sensitivity analysis.

[32] E-cigarette product characteristics were identified for 96.3% of an average year's e-cigarette sales volume as identified by the NielsenIQ data.

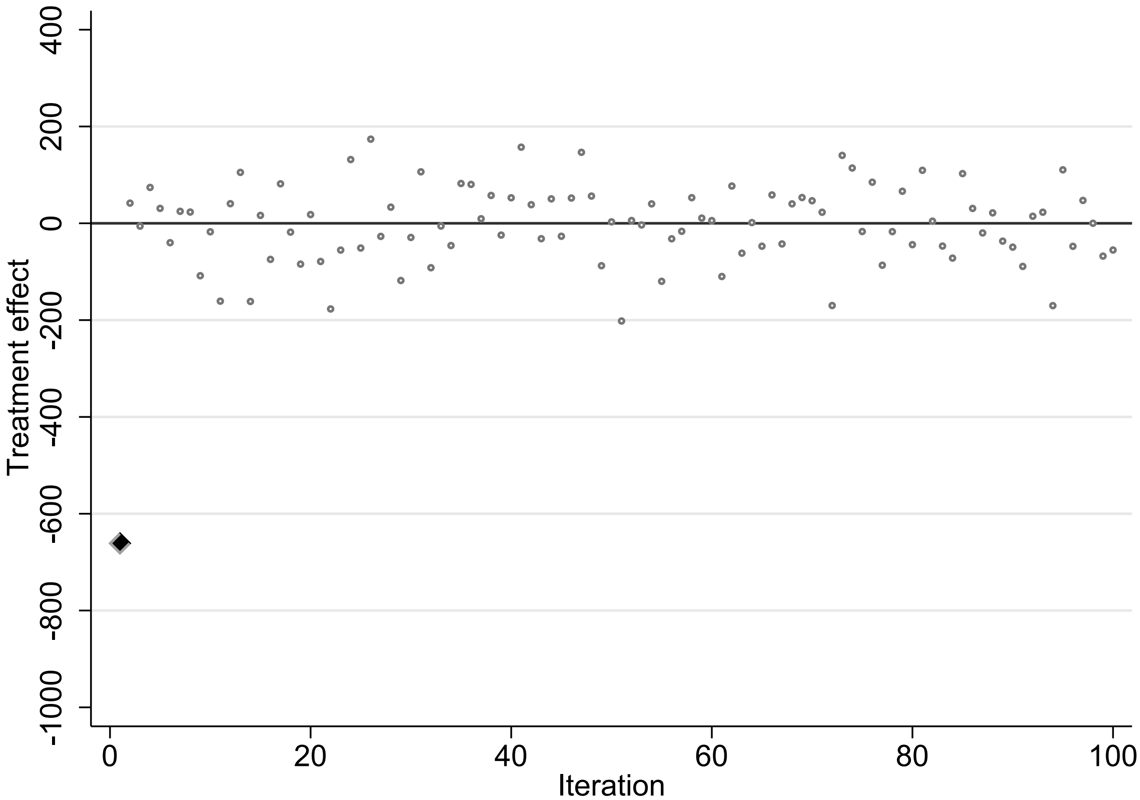
[33] For Cook County, we do not have the ability to separate Chicago from the rest of Cook County in the NielsenIQ data. For the Chicago portion of the tax, Chicago uses a $0.55 tax per ml of fluid and a $0.80 tax per container of products containing liquid nicotine (e.g., cartridge, disposable). Since Chicago constitutes approximately 52.1% of the population of Cook County in 2017, we weight the Chicago tax by this share of the population to approximate the Cook County tax. Cook County later passed its own tax per fluid ml that we add in whole to the weighted tax from Chicago.

Online Appendix Figure 1. Effect of e-cigarette taxes on e-cigarette prices using a placebo test: NielsenIQ retail sales UPC-level data 2011-2017



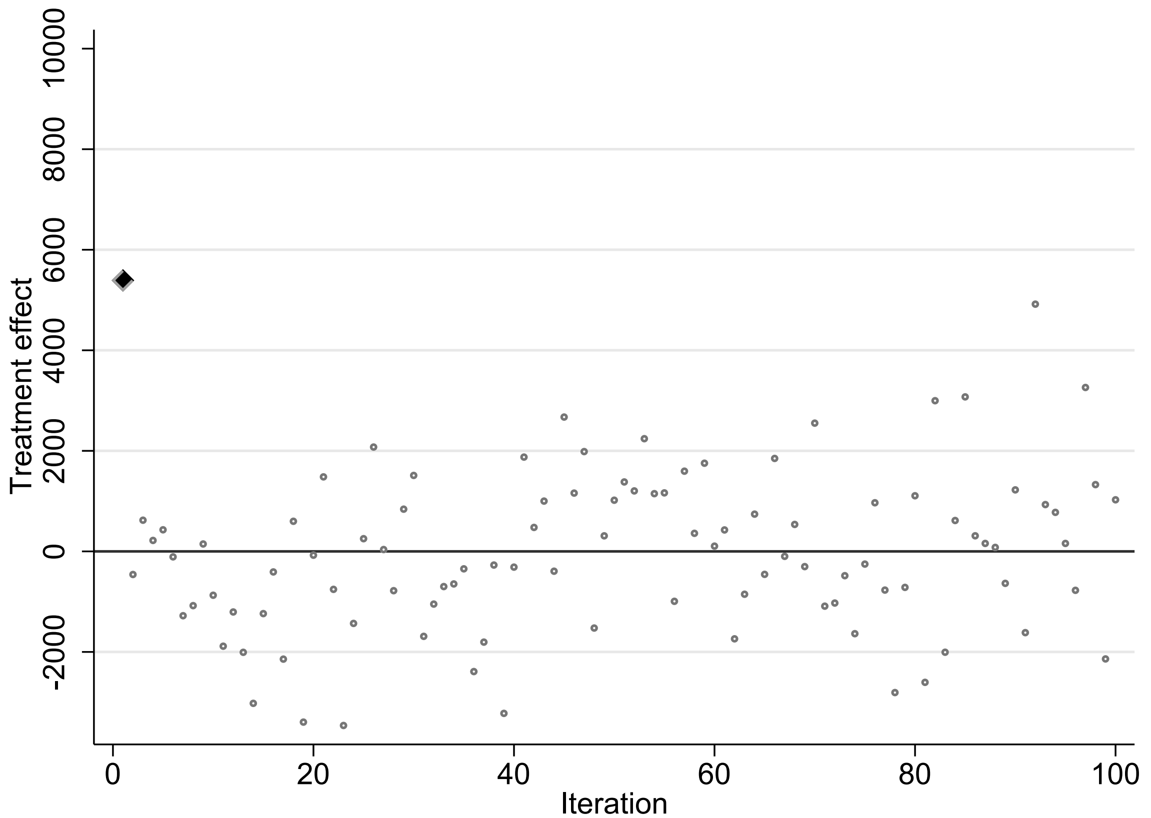
Notes: The unit of observation is a UPC-code in a locality (state or county) in a quarter (quarter-by-year). The model is estimated with least squares and controls for time-varying locality characteristics, UPC-by-locality fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the share of e-cigarette sales in localities that do not adopt an e-cigarette tax. The black diamond is the coefficient estimate from our preferred specification. The small white circles capture coefficient estimates generated in equation (1) after randomly re-shuffling e-cigarette taxes across localities and periods.

Online Appendix Figure 2. Effect of e-cigarette taxes on e-cigarette sales per 100,000 using a placebo test: NielsenIQ state-level sales data 2011-2017



Notes: The unit of observation is a locality (state or county) in a quarter (quarter-by-year). The model is estimated with least squares and controls for time-varying locality characteristics, state fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the locality population. The black diamond is the coefficient estimate from our preferred specification. The small white circles capture coefficient estimates generated in equation (1) after randomly re-shuffling e-cigarette taxes across localities and periods.

Online Appendix Figure 3. Effect of e-cigarette taxes on cigarette sales using a placebo test: NielsenIQ state-level sales data 2011-2017



Notes: The unit of observation is a locality (state or county) in a quarter (quarter-by-year). The model is estimated with least squares and controls for time-varying locality characteristics, state fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the locality population. The black diamond is the coefficient estimate from our preferred specification. The small white circles capture coefficient estimates generated in equation (1) after randomly re-shuffling e-cigarette taxes across localities and periods.

Online Appendix Table 1. E-cigarette tax adoption through the end of 2017

Locality	Effective date	Unit taxed	Tax amount	Tax value quarter four in 2017 ($)
State				
California	4/2017, 7/2017	Wholesale price	27.3%, 65.1%	1.24
Washington, DC	10/2015, 10/2016, 10/2017	Wholesale price	67%, 65%, 60%	1.14
Kansas	1/2017, 7/2017	Per fluid milliliter	$0.20, $0.05	0.05
Louisiana	7/2015	Per fluid milliliter	$0.05	0.05
Minnesota	8/2010, 7/2013	Wholesale price	35%, 95%	1.81
North Carolina	6/2015	Per fluid milliliter	$0.05	0.05
Pennsylvania	7/2016	Wholesale price	40%	0.76
West Virginia	7/2016	Per fluid milliliter	$0.075	0.075
County/City				
Chicago, Illinois	1/2016	Per container / per fluid milliliter	$0.80 / $0.55	0.83^
Cook County, Illinois	5/2016	Per fluid milliliter	$0.20	0.83^
Montgomery County, Maryland	8/2015	Wholesale price	30%	0.57

Notes: See text for full details. ^ The Chicago tax is added to the Cook County tax based on the share of the population residing in Chicago, see the appendix for further details.

Online Appendix Table 2. Effect of e-cigarette taxes on e-cigarette prices using a two-way fixed effects model excluding treated localities one at a time tax (*leave one out analysis)*: NielsenIQ retail sales UPC-level data 2011-2017

Outcome:	**E-cigarette price ($)**
Mean: E-cigarette tax adopting localities, year prior to the tax ($)†	3.666
Exclude California	
E-cigarette tax ($)	1.434***
	(0.155)
Observations	89121
Exclude Cook County, IL	
E-cigarette tax ($)	1.584***
	(0.091)
Observations	89744
Exclude Washington DC	
E-cigarette tax ($)	1.335***
	(0.167)
Observations	90186
Exclude Kansas	
E-cigarette tax ($)	1.440***
	(0.143)
Observations	89757
Exclude Louisiana	
E-cigarette tax ($)	1.425***
	(0.140)
Observations	89286
Exclude Minnesota	
E-cigarette tax ($)	1.339***
	(0.160)
Observations	89876
Exclude Montgomery County, MD	
E-cigarette tax ($)	1.476***
	(0.152)
Observations	90003
Exclude North Carolina	
E-cigarette tax ($)	1.438***
	(0.143)
Observations	89249
Exclude Pennsylvania	
E-cigarette tax ($)	1.463***
	(0.157)
Observations	89157
Exclude West Virginia	
E-cigarette tax ($)	1.433***
	(0.142)
Observations	89480

Notes: The unit of observation is a UPC-code in a locality (state or county) in a quarter (quarter/year). All models estimated with least squares and control for time-varying locality characteristics, UPC-by-locality fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the share of e-cigarette sales in localities that do not adopt an e-cigarette tax. Standard errors that account for within-locality clustering are reported in parentheses.
†Mean values are based on the full sample of e-cigarette adopting localities, pre-tax.
***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

Online Appendix Table 3. Test of covariate balance

Outcome	E-cigarette tax ($)
Cigarette tax ($)	0.353***
	(0.079)
Full smoking ban	0.010
	(0.065)
% covered by indoor vaping ban	-0.070
	(0.130)
Share of border localities without an e-cigarette tax	-0.012
	(0.096)
Vape-free public K-12 schools	0.035
	(0.043)
Smoke-free public K-12 schools	-0.031
	(0.027)
Tobacco 21 law	0.128
	(0.096)
Beer tax ($)	0.010
	(0.020)
ACA Medicaid expansion	-0.001
	(0.023)
Unemployment rate	0.003
	(0.011)
Age	-0.010
	(0.012)
Female	-0.591
	(0.413)
African American	-0.816
	(1.620)
Other race	-0.164
	(0.374)
Hispanic	-0.002
	(0.001)
Born outside the U.S.	-0.500
	(0.691)
High school	-0.110
	(0.501)
Some college	-1.064**
	(0.434)
College	-0.326
	(0.459)
Population (millions)	0.014
	(0.014)
F-statistic for joint significance of time-varying covariates	364.71
(*p*-value)	(<0.0000)
Mean e-cigarette tax ($)	0.047
Observations	1428

Notes: The unit of observation is a locality (state or county) in a quarter (quarter-by-year). All models estimated with least squares and control for locality fixed effects, and period (quarter-by-year) fixed effects. Omitted categories are male, white, non-Hispanic, born in the U.S., and less than high school education. Data are weighted by state population. Standard errors that account for within-locality clustering are reported in parentheses.
***, **, and * = statistically different from zero at the 1%, 5%, and 10% level.

Online Appendix Table 4A. Effect of e-cigarette taxes on e-cigarette and cigarette sales per 100,000 state adult residents using a two-way fixed effects model, alternative samples: NielsenIQ retail sales locality-level data 2011-2017

Outcome:	**E-cigarettes**	**Cigarettes**
Mean: E-cigarette tax adopting localities, year prior to the tax†	1,307	56,470
Exclude divisions with no adopting localities by 2017††		
E-cigarette tax ($)	-566***	11,265***
	(185)	(3,289)
Observations	924	924
Drop enactment period		
E-cigarette tax ($)	-786***	11,991**
	(231)	(4,543)
Observations	1408	1408
Drop treated state localities		
E-cigarette tax ($)	-779***	11,290**
	(221)	(5,123)
Observations	1372	1372
Drop treated sub-state localities		
E-cigarette tax ($)	-684**	12,639**
	(275)	(6,153)
Observations	1372	1372
Drop 2011-2012		
E-cigarette tax ($)	-563**	10,964**
	(217)	(4,768)
Observations	1020	1020
Use excise tax localities only (exclude localities with ad valorem taxes)		
E-cigarette tax ($)	-1,094***	8,985
	(189)	(7,038)
Observations	1288	1288
Use ad valorem tax localities only (standardized in dollars; exclude localities with excise taxes)		
E-cigarette tax ($)	-782***	13,721**
	(268)	(6,673)
Observations	1288	1288
Use ad valorem tax localities only (non-standardized in percent; exclude localities with excise taxes)		
E-cigarette tax (percentage point)	-14***	230*
	(5)	(122)
Observations	1288	1288
Drop border counties		
Mean: E-cigarette tax adopting localities, year prior to the tax	751	32,682
E-cigarette tax ($)	-754**	15,997*
	(325)	(8,318)
Observations	1344	1344

Notes: The unit of observation is a locality (state or county) in a quarter (quarter-by-year). All models estimated with least squares and control for time-varying locality characteristics, locality fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the locality population. Standard errors that account for within-locality clustering are reported in parentheses.
***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.
†Based on the full sample.
†† Excluded divisions: New England, East South Central, and Mountain.

Online Appendix Table 4B. Effect of e-cigarette taxes on e-cigarette and cigarette sales per 100,000 state adult residents using a two-way fixed effects model, alternative specifications: NielsenIQ retail sales locality-level data 2011-2017

Outcome:	**E-cigarettes**	**Cigarettes**
Mean: E-cigarette tax adopting localities, year prior to the tax	1,307	56,470
Include division-by-quarter fixed effects		
E-cigarette tax ($)	-675***	19,967***
	(180)	(6,371)
Unweighted		
E-cigarette tax ($)	-866**	15,143***
	(342)	(4,472)
Weight by quarterly e-cigarette sales in 2013		
E-cigarette tax ($)	-775***	10,699**
	(216)	(4,060)
Use alternative e-cigarette tax variable†		
E-cigarette tax ($)	-681***	12,203***
	(161)	(4,300)
Control for the enactment period		
E-cigarette tax ($)	-763***	10,661**
	(211)	(4,611)
Lag e-cigarette tax one quarter		
E-cigarette tax ($)	-711***	10,791***
	(242)	(3,773)
Lag e-cigarette tax one year		
E-cigarette tax ($)	-888***	10,700**
	(152)	(4,488)
Control for political variables		
E-cigarette tax ($)	-772***	10,276**
	(216)	(4,151)
Use e-cigarette tax variable using only refills††		
Mean: E-cigarette tax adopting localities, year prior to the tax	873	56,470
E-cigarette tax ($)	-447	14,786**
	(363)	(6,327)
Observations	1428	1428

Notes: The unit of observation is a locality (state or county) in a quarter (quarter-by-year). All models estimated with least squares and control for time-varying locality characteristics, locality fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the locality population. Standard errors that account for within-locality clustering are reported in parentheses.

† Using market information specific to each locality, rather than across non-adopting localities. See the appendix for additional details.

†† A wholesale price estimate for refills of $3.52 is used in the standardization, as explained in the appendix.

***, **, and * = statistically different from zero at the 1%, 5%, and 10% level.

Online Appendix Table 5. Effect of e-cigarette taxes on e-cigarette and cigarette sales per 100,000 adults using a two-way fixed-effects model (*leave one out analysis)*: NielsenIQ state-level sales data 2011-2017

Outcome:	**E-cigarettes**	**Cigarettes**
Mean: E-cigarette tax adopting localities, year prior to the tax†	1,307	56,470
Exclude California		
E-cigarette tax ($)	-968***	12,821**
	(220)	(5,395)
Exclude Cook Co, IL		
E-cigarette tax ($)	-676**	13,802**
	(269)	(6,140)
Exclude Washington DC		
E-cigarette tax ($)	-774***	11,095**
	(218)	(4,884)
Exclude Kansas		
E-cigarette tax ($)	-774***	10,432**
	(207)	(4,467)
Exclude Louisiana		
E-cigarette tax ($)	-793***	11,259**
	(203)	(4,793)
Exclude Minnesota		
E-cigarette tax ($)	-586***	10,794**
	(176)	(4,396)
Exclude Montgomery Co, MD		
E-cigarette tax ($)	-764***	10,458**
	(211)	(4,475)
Exclude North Carolina		
E-cigarette tax ($)	-766***	12,445**
	(209)	(4,751)
Exclude Pennsylvania		
E-cigarette tax ($)	-746***	11,653**
	(257)	(4,624)
Exclude West Virginia		
E-cigarette tax ($)	-759***	11,024**
	(207)	(4,586)
Observations	1400	1400

Notes: The unit of observation is a locality (state or county) in a quarter (quarter/year). All models estimated with two-stage least squares and control for time-varying locality characteristics, locality fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by the locality population. Standard errors that account for within-locality clustering are reported in parentheses.
†Based on the full sample.
***, **, and * = statistically different from zero at the 1%, 5%, and 10% level.

Online Appendix Table 6. Effect of e-cigarette and cigarette prices on sales per 100,000 adults instrumenting the e-cigarette price with the e-cigarette tax and instrumenting the cigarette price with the cigarette tax (*leave one out analysis)*: NielsenIQ state-level sales data 2011-2017

Outcome:	**E-cigarettes**	**Cigarettes**
Mean: E-cigarette tax adopting localities, year prior to the tax†	1,307	56,470
Mean: Cigarette tax adopting localities, year prior to the first cigarette tax increase†	1,194	70,079
Exclude California		
E-cigarette price ($)	-563***	7,581**
	(104)	(2,996)
Cigarette price ($)	12	-3,932
	(100)	(3,342)
Exclude Cook Co, IL		
E-cigarette price ($)	-369**	7,575***
	(144)	(2,867)
Cigarette price ($)	268***	-7,615***
	(90)	(2,591)
Exclude Washington DC		
E-cigarette price ($)	-377***	5,466**
	(106)	(2,303)
Cigarette price ($)	232**	-4,732*
	(92)	(2,517)
Exclude Kansas		
E-cigarette price ($)	-383***	5,207**
	(103)	(2,146)
Cigarette price ($)	239**	-4,303*
	(94)	(2,347)
Exclude Louisiana		
E-cigarette price ($)	-408***	5,840**
	(103)	(2,429)
Cigarette price ($)	247***	-4,943*
	(93)	(2,565)
Exclude Minnesota		
E-cigarette price ($)	-296***	5,444**
	(95)	(2,194)
Cigarette price ($)	272***	-4,852*
	(71)	(2,651)
Exclude Montgomery Co, MD		
E-cigarette price ($)	-384***	5,324**
	(104)	(2,216)
Cigarette price ($)	235**	-4,607*
	(93)	(2,459)
Exclude North Carolina		
E-cigarette price ($)	-381***	6,223***
	(104)	(2,399)
Cigarette price ($)	231**	-4,678*
	(93)	(2,559)
Exclude Pennsylvania		
E-cigarette price ($)	-359***	5,670***
	(123)	(2,185)
Cigarette price ($)	231**	-4,891*
	(94)	(2,546)
Exclude West Virginia		
E-cigarette price ($)	-380***	5,559**

	(104)	(2,256)
Cigarette price ($)	238***	-4,610*
	(91)	(2,480)
Observations	1400	1400

Notes: The unit of observation is a locality (state or county) in a quarter (quarter/year). All models estimated with two-stage least squares and control for time-varying locality characteristics, locality fixed effects, and period (quarter-by-year) fixed effects. Data are weighted by locality population. Standard errors that account for within-locality clustering are reported in parentheses.
***, **, and * = statistically different from zero at the 1%, 5%, and 10% level.
†Based on the full sample.