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The Effects of E-Cigarette Taxes on E-Cigarette Prices and Tobacco Product Sales: Evidence from Retail Panel Data
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ABSTRACT

We estimate 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 Nielsen Retail Scanner data from 2011 to 2017, comprising approximately 35,000 retailers nationally. We develop a method to standardize e-cigarette taxes as adopting localities have taxed these products in heterogeneous ways. We estimate a tax-to-price pass-through rate of 1.5. We calculate a Herfindahl–Hirschman Index of 0.245 for e-cigarette retail purchases, indicating a moderately to highly concentrated market that has been theoretically linked to over-shifting of taxes. We then calculate an e-cigarette own-price elasticity of -1.3 and positive cross-price elasticities of demand between e-cigarettes and traditional cigarettes, suggesting an economic substitutionary relationship. We also find that taxes disproportionately reduce flavored e-cigarette sales and cause large substitution toward mentholated traditional cigarettes.

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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 March 15, 2020, 23 states have enacted an e-cigarette tax (Public Health Law Center 2020). Despite the rapid increase in e-cigarette use, very little is known about the effects of these policies on the use of e-cigarettes or other tobacco products.

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 Nielsen Retail Scanner Data (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 identify purchases and sales of e-cigarettes and other tobacco products in the NRSD, and we match 94.5% of e-cigarette product sales to detailed product characteristics, including product type, liquid volume, and nicotine content. Access to these characteristics allows for a comprehensive investigation of the impacts of taxation on ingredient consumption as well as a more accurate standardization of the e-cigarette taxes themselves, which are often levied based on the quantity of liquid contained in the product.

We first estimate the pass-through rate of e-cigarette and traditional cigarette taxes to the prices of these goods, finding that e-cigarette taxes are more than fully passed through to e-

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

cigarette prices. We then estimate how sales of e-cigarettes and other tobacco products respond to changes in e-cigarette taxes. We find that the demand for e-cigarettes is elastic, with an estimated price elasticity of demand of -1.3. We additionally find that fruit, or other flavored e-cigarettes have a higher price elasticity of demand than either tobacco or menthol/mint flavored e-cigarettes. We calculate a Herfindahl–Hirschman Index of 0.245 for e-cigarette retail purchases. This result suggests that the e-cigarette retail market is highly concentrated, which is a market structure where over-shifting of taxes to prices is possible. We show that traditional cigarette sales increase following a rise in e-cigarette taxes, suggesting that e-cigarettes and traditional cigarettes are economic substitutes with an e-cigarette cross-price elasticity of demand of 0.8 and a traditional cigarette cross-price elasticity of demand of 1.4. We document a price-elasticity of demand for traditional cigarettes of -0.8, which is in line with previous studies, although larger in magnitude than some of the more recent work (for reviews, see Chaloupka and Warner 2000, DeCicca et al. 2018).

Our paper is among the first to estimate the pass-through rate for e-cigarette taxes. Examination of the intensive margin requires standardizing different forms of e-cigarette taxes to measure the magnitude of the tax. Standardization is complicated given heterogeneity in the ways in which localities have elected to tax e-cigarettes. Many e-cigarette taxes are not levied per unit as are traditional cigarette taxes, but rather as ad valorem taxes. Our paper develops a novel method to standardize the taxes. Exploration of the intensive tax margin is important because the standardized magnitudes of existing e-cigarette taxes vary widely, from $0.05 per milliliter (ml) in Kansas and Louisiana to $1.85 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) in the NRSD to the volume of liquid of these e-cigarettes using internet searches, correspondences with companies, and visits to retailers. The database of characteristics, which also includes product type, liquid flavor, and nicotine content, was developed by Cotti, Nesson, and Tefft (2018). We have updated the database to include newer products and are the first study to use it to study the effects of any e-cigarette-related policies. These additional product characteristics allow us to standardize e-cigarette taxes that are often levied per ml of vaping liquid. Thus, we are among the first research groups in the economics literature to estimate the dollar-to-dollar pass-through rate of e-cigarette taxes to e-cigarette prices and the price elasticity of demand for e-cigarettes, and we are the first research group to examine heterogeneity in e-cigarette price elasticity of demand by e-cigarette flavors. This extension is important given the policy importance of flavored e-cigarettes, for example, there have been calls to fully ban flavored e-cigarettes nationally in the U.S.[2]

Using the NRSD allows us to examine e-cigarette purchases within the general population much earlier than is possible with other datasets of which we are aware.[3] In particular, we track e-cigarette purchases beginning in 2011 in the NRSD, while common survey datasets used within the economics literature to study tobacco products did 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). Use of this early time period enables us to leverage additional policy variation and a more rigorous investigation of pre-treatment trends between localities that adopt and do not adopt an e-cigarette tax.

[2] Indeed, in January 2020, the Trump Administration banned the sale of select flavors sold in e-cigarette cartridges.
[3] 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.

The rest of this paper is organized as follows. Section 2 provides background and a review of the literature surrounding e-cigarette use, Section 3 summarizes our data sources, Section 4 describes our methodology, Section 5 reviews the results, and Section 6 concludes.

2. Literature Review and Background

In a perfectly competitive market, the rate at which a tax change impacts the after-tax price (i.e., the 'pass-through rate') is a function of the elasticities of both supply and demand and ranges from zero and one. 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 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 traditional cigarette market. For example, one study uses American Chamber of Commerce Research Association data 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. Bread has the highest pass-through rate of the 12 products at 2.42 (Besley and Rosen 1999).

Several recent studies use national-level data to evaluate the effect of traditional cigarette tax increases on traditional 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 (TUS) to estimate the pass-through rate of traditional cigarette taxes to consumer prices ranging from 0.91 to 1.18, with some evidence that pass-through rate is lower for higher intensity smokers. Rozema and Ziebarth (2017) use individual-level data on prices paid for traditional 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 traditional cigarette prices from retail locations in Wisconsin and border states to evaluate the effects of large increases in traditional 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 traditional cigarette tax pass-through rate of 0.85. The authors use a UPC-level rather than a state-level model to hold product quality constant. Overall, their findings provide a series of pass-through rate estimates ranging from 0.80 to 1.18 when studying traditional cigarette taxes.

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 studies on pass-through rate 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.

Relatedly, a growing literature examines the relationship between e-cigarettes and traditional cigarettes. Because variation in e-cigarette policies, particularly e-cigarette taxes, is recent and data on e-cigarettes have not been readily available, much of the research to date on the relationship between e-cigarettes and traditional cigarettes has examined the effects of e-cigarette restrictions (rather than taxes) on the demand for traditional cigarettes (rather than e-cigarettes). For example, Friedman (2015) uses the National Survey on Drug Use and Health and finds that states implementing restrictions on youth access to e-cigarettes see increases in youth past 30 day smoking rates, suggesting that e-cigarettes and traditional cigarettes are substitutes among adolescents. Similarly, Pesko, Hughes, and Faisal (2016) and Dave, Feng, and Pesko (2019) use the Youth Risk Behavior Surveillance System data and restrictions on adolescent access to e-cigarettes, finding evidence that the two products are substitutes for this population. Pesko and Currie (2019) have comparable findings for pregnant adolescents using birth record data. Contrary to these findings, Abouk and Adams (2017) use the same restrictions on adolescent access to e-cigarettes and individual-level data for underage high school seniors from Monitoring the Future Survey (MTF) to find that the products are economic complements. Finally, Dave et al. (2019) finds that exposure to e-cigarette advertising helps adult smokers quit smoking.

Few studies estimate the effect of tobacco control policies on e-cigarette use itself. One exception is Cotti, Nesson, and Tefft (2018). The authors examine the effects of traditional cigarette taxes and other tobacco control policies, including indoor vaping restrictions (IVRs) and indoor smoking restrictions (ISRs), on adult households' purchases of e-cigarettes and other tobacco products using the Nielsen Consumer Panel data. The authors document that traditional cigarette tax increases induce households to purchase fewer e-cigarette products, suggesting a complementary relationship between e-cigarettes and traditional cigarettes. Both Abouk and Adams (2017), and Dave, Feng, and Pesko (2019) provide evidence from a single wave of data that age purchasing restrictions reduce e-cigarette use.

Recently, increasingly available data and the presence of new e-cigarette policies have led to additional examinations of e-cigarette tax effects on e-cigarette use. One working paper provides some evidence that the e-cigarette tax increase in Minnesota in 2013 reduces e-cigarette use and increases traditional cigarette use among adolescents (Pesko and Warman 2019). Two other papers show that higher e-cigarette tax rates reduce e-cigarette use and increase traditional cigarette use (i.e., economic substitution) for adults (Pesko, Courtemanche, and Maclean 2020) and pregnant women (Abouk et al. 2020), and symmetrical effects with traditional cigarette taxes. The latter two papers use the standardized e-cigarette tax method developed in this paper, and none use as long a time period for e-cigarette outcomes or as much policy variation as we use in our work.

A paper by Saffer et al. (2020) also uses survey data, the TUS 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 a cross elasticity of current smoking participation with respect to e-cigarette prices of 0.13. Assuming a retailer markup of 33% over the wholesale costs, the authors estimate a tax-pass-through rate to price in Minnesota of 1.33. Relative to this paper, we utilize substantially more policy variation, as we leverage the experiences of all e-cigarette tax adopting localities between 2011 and 2017 rather than a single state, we examine heterogeneity in the e-cigarette price elasticity of demand by liquid flavors, and we explore tax effects on a range of tobacco products.

Other studies estimate the effect of e-cigarette prices, rather than taxes, on e-cigarette demand. The NRSD is used in two studies to study the effect of e-cigarette prices on e-cigarette and traditional cigarette sales. Huang et al. (2018) use data from 2007 to 2014 to document e-cigarette own-price elasticities for rechargeable e-cigarette sales of -1.4 and for disposable e-cigarette sales of -1.5. Using data over the period 2009 to 2013 Zheng et al. (2017) estimate an e-cigarette own-price elasticity of demand of -2.1, a cross-price elasticity of traditional cigarette prices on e-cigarettes sales of 1.9, and a cross-price elasticity of e-cigarette prices on traditional cigarette sales of 0.004. Using European data over the period 2011 to 2014, Stoklosa, Drope, and Chaloupka (2016) document an e-cigarette own-price elasticity of demand of -0.8 and a cross-price elasticity of traditional cigarette prices on e-cigarette sales of 4.6. Pesko et al. (2016) use a discrete choice experiment to estimate an e-cigarette own-price elasticity among current adult smokers of -1.8.

Survey data are used in three studies to estimate the effect of e-cigarette prices on e-cigarette *use* rather than sales. Saffer et al. (2018) use data on adults from the 2014 to 2015 TUS to estimate an e-cigarette price elasticity of vaping participation of -1.2. Pesko et al. (2018) use two years of the MTF data on middle and high school students and find a -1.8 own price elasticity of days vaping. Cantrell et al. (2019) use national longitudinal cohort data on a sample of 15- to 21-year-olds from 2014 to 2016 and find no effect of e-cigarette prices on vaping, but a traditional cigarette cross-price elasticity of 0.9. Of course, the endogeneity of prices is a potential limitation of these papers, and we aim to overcome this challenge by using plausibly exogenous variation from the implementation of taxes.

Lastly, in a working paper Allcott and Rafkin (2020) use a different identification strategy than the previously mentioned studies to estimate whether e-cigarettes and traditional cigarettes are economic substitutes or complements. Using all known available survey data for the U.S., the authors use the pre-2013 smoking propensities for 800 adult demographic cells 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.[4]

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[4] Allcott and Rafkin (2020) also estimate IV models to estimate cross-price elasticities. In Table 2, they find some evidence that traditional cigarette prices are positively associated with e-cigarette sales. In Appendix Table A2, they

Allcott and Rafkin's working paper was written concurrently to and independently from ours and, while their primary objectives and ours 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 (IV) model estimating the price elasticity of demand for use in welfare calculation, rather than as an attempt to measure the pass-through rate. Accordingly, Allcott and Rafkin use a logarithmic, rather than 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 specific 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 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 D.C.'s ad valorem tax that is set to parity with the traditional 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 paper and theirs complement each other in that both offer evidence on the relationship between e-cigarettes and traditional cigarettes.

3. Data

a. Nielsen Retail Scanner Data (NRSD)

examine the effect of e-cigarette prices on the demand for traditional cigarettes. Here, they find evidence that higher e-cigarette prices increase sales of traditional 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 when the treatment variable leads to a change in outcome trends can be problematic. Hence, we interpret findings based on regression models that include area-specific linear time trends with some caution.

Our main data source is the 2011 to 2017 NRSD. The NRSD comprises a sample of approximately 30,000 to 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). From these data, we include all retailers that sell e-cigarette or tobacco products in our analysis. The volume of each UPC purchased at each store is recorded weekly, as well as the average price paid, including all taxes except sales taxes. In part to account for retailers switching brands or products in response to tax changes, we then calculate the average e-cigarette price at both the UPC-locality-quarter level and locality-quarter level, where 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] These prices are weighted averages, by the quantity of sales, across all UPCs and stores and within the given level of aggregation.

We analyze sales data on five tobacco product categories: e-cigarettes, traditional cigarettes, cigars, chewing tobacco, and loose tobacco. Measuring e-cigarette sales in the NRSD presents some challenges. First, e-cigarette products in the NRSD are heterogeneous. Some are disposable e-cigarettes, while others are starter kits or refill cartridges. Further, the quantity of cartridges, liquid, and nicotine varies widely within products of the same type. Second, many e-cigarette taxes are levied in proportion to the liquid volume in each e-cigarette product, while others are levied as ad valorem taxes. This regulatory pattern is distinct from traditional cigarette taxes, which are nearly all levied in terms of dollars per traditional cigarette. Finally, previous

[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.

research suggests that measuring traditional cigarette consumption only through the number of products used provides an incomplete picture of smokers' behavior in response to policy changes. In particular, smokers may respond to traditional cigarette taxes by altering the type of traditional cigarette they smoke or how they smoke the product (Cotti, Nesson, and Tefft 2016, Nesson 2017a, b, Adda and Cornaglia 2006, Evans and Farrelly 1998). None of these behavioral responses are captured by the number of products consumed but all are important for evaluating the overall effect of a tax adoption. Vapers may plausibly display comparable behavioral responses to e-cigarette policies, and we wish to capture such responses in our analysis.

To address these challenges, we estimate our main models of e-cigarette sales using the liquid volume in each e-cigarette, as in Cotti, Nesson, and Tefft (2018). We match UPCs in the NRSD to additional product characteristics using correspondences with e-cigarette companies, internet searches, and in-person visits to retailers conducted by members of the research team. We first record the type of e-cigarette product for each UPC, classifying products into disposable e-cigarettes, starter kits, and cartridge refills.[6] Second, we calculate the milliliters (mls) of fluid in each e-cigarette UPC. Third, we identify the flavor of the e-cigarette. We are able to match 94.5% of the e-cigarette products by the value of sales in the NRSD to tobacco product characteristics in this way.

For the other tobacco products, we create variables counting the sales for each product in terms of the units provided by Nielsen. We thus separately count the number of traditional cigarettes, which we aggregate into 20 unit packs, the number of cigars, the ounces of chewing tobacco, and the ounces of loose tobacco sold.

b. Tobacco Control Policies

[6] Starter kits include a reusable battery and atomizer along with a selection of disposable cartridges.

We use three policy data sources to construct our e-cigarette tax variable. State-level e-cigarette tax data is drawn from the Public Health Law Center (Public Health Law Center 2020) and the CDC 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). To date, 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, and Chicago 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 Alaskan counties also levy e-cigarette taxes, but Alaska is not included in the NRSD and is therefore not included in our standardization procedure. Appendix Table 1 provides information on the effective dates, unit taxed, tax amount, and relative tax value (in 2017 Q4) for each e-cigarette tax law implemented during the time frame of NRSD data utilized in this study.

Washington DC is unique in that this locality set the ad valorem tax rate at 100% of the traditional cigarette tax, suggesting that each one percentage point of ad valorem e-cigarette tax is 4.3 cents. We use this relationship to convert e-cigarette ad valorem taxes into unit tax equivalents for each relevant locality. Please see the appendix for a detailed discussion of our conversion.

Between the end of our study period (December 2017) and March 15, 2020, 15 additional states enacted new e-cigarette laws: Connecticut, Delaware, Illinois, Maine, Massachusetts, Nevada, New Hampshire, New Jersey, New Mexico, New York, Ohio, Vermont, Washington, Wisconsin, and Wyoming (Public Health Law Center 2020).[7]

We collect data on traditional cigarette unit taxes from the CDC STATE System and transform these into the traditional cigarette unit taxes measured in real 2017 dollars (using the Consumer Price Index-Urban Consumers [CPI]) in each state and quarter (Centers for Disease Control and Prevention 2019b). Two states (California and New Jersey) enacted Tobacco 21 laws by the end of 2017 and we include an indicator for this policy (Campaign for Tobacco-Free Kids 2019b).[8]

Additionally, we collect data on indoor air laws from the American Non-Smokers' Rights Foundation (ANR). ANR 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 IVRs and ISRs for private workplaces, restaurants, or bars. For both IVRs and ISRs, we weight laws applying to bars, restaurants, and private workplaces equally. For ISRs, we also consider laws applying to only part of the establishment (but not the full establishment) with ½ weight.[9] Additionally, we collect state laws banning smoking and vaping in K-12 public schools from the CDC STATE system (Centers for Disease Control and Prevention 2019b).

4. Methods

We implement a standard two-way fixed effects identification strategy that connects variation in retailers' e-cigarette prices to changes in tobacco control policies. That is, we leverage

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[7] We have incorporated tax adoptions that occur after the end of our study period, i.e., those that occur 2018 through 2020, in an event-study. Results are not appreciably different.
[8] Hawaii also enacted a Tobacco 21 law before the end of 2017; however, the Nielsen data is limited to the contiguous 48 states and so Hawaii is not included.
[9] These partial laws were uncommon for IVRs.

variation in locality-level tobacco control policies that occur between 2011 and 2017 to identify treatment effects. Specifically, we estimate:

(1) $$Y_{i,l,t} = \beta_0 + \beta_E Etax_{l,t} + \beta_T Ttax_{l,t} + W_{l,t}\beta_W + X_{l,t}\beta_X + \sigma_{l,i} + \tau_q + \varepsilon_{i,l,t},$$

where $Y_{i,l,t}$ the price for e-cigarette product (i.e., UPC Code) *i* in locality *l* and quarter *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 product-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 enacted an e-cigarette tax by the end of 2020 as the weight.[10] We measure both e-cigarette taxes ($Etax_{l,t}$) and traditional cigarette unit taxes ($Ttax_{l,t}$). $Etax_{l,t}$ is a continuous variable measuring the magnitude of e-cigarette taxes as described in Section 3.b and the appendix. $Ttax_{l,t}$ is a continuous variable measuring the locality-level traditional cigarette unit tax per pack.

We include additional tobacco control policies in $W_{l,t}$: (1) a vector of ISRs and IVRs (measured as the percent of the locality's population living under an ISR, and separately as the percent of the locality's population living under an IVR), (2) state laws banning smoking and vaping in K-12 public schools, and (3) whether the locality borders another locality with an e-cigarette tax (a proxy for tax avoidance propensity (Ghimire and Maclean 2020, Maclean, Webber, and Marti 2014)). We also include locality-level characteristics in $X_{l,t}$: beer tax, the Affordable Care Act's Medicaid expansions,[11] the Bureau of Labor Statistics' unemployment rate, and Current

[10] 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.
[11] https://www.kff.org/health-reform/state-indicator/state-activity-around-expanding-medicaid-under-the-affordable-care-act. Last accessed on 8/8/2020.

Population Survey demographics (e.g., age, sex, and race/ethnicity). We also include UPC-by-locality and quarter fixed effects in our regression models, represented by $\sigma_{i,l}$ and τ_y, respectively, following Harding et al. (2013). The product fixed effects hold product availability, and other attributes such as quality, 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 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 CPI.

After examining the pass-through rate of e-cigarette taxes to e-cigarette prices, we next examine whether e-cigarette prices and traditional 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 product-by-locality-by-quarter aggregation in equation (1) to permit new product offerings to influence tax responsiveness. Our approach closely follows Harding, Leibtag, and Lovenheim (2012). 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 traditional cigarettes in response to the tax. Separately, they estimate state fixed effects models for sales outcomes in order to avoid restricting traditional cigarette products to those UPCs existing both before and after the tax (not the only products that contribute identifying variation in sales outcomes).

We examine five categories of tobacco products: e-cigarettes, traditional cigarettes, cigars, chewing tobacco, and loose tobacco. We also examine non-flavored and flavored e-cigarettes and traditional cigarettes separately. To this end, we separate e-cigarettes into three flavored categories using our hand-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 traditional cigarettes into regular cigarettes and menthol cigarettes using flavor information available in the NRSD.

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

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

Here, $Y_{l,t}$ represents the 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, using Stata's *semipar* command (Robinson 1988), in the relationship between e-cigarette taxes and e-cigarette sales that would support log-transforming the dependent variable. We weight equation (2) regressions using the population in that locality and cluster standard errors at the locality level.

We are also interested in studying the impact of prices on tobacco product purchases. An obvious problem with estimating this relationship however is that e-cigarette and traditional cigarette prices are endogenously determined. Therefore, we simultaneously instrument for e-cigarette and traditional cigarette prices with e-cigarette and traditional cigarette taxes in a two-stage least squares (IV) regression:

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

where $EP_{l,t}$ and $TP_{l,t}$ are now replaced with their predicted values, $\widehat{EP}_{l,t}$ and $\widehat{TP}_{l,t}$, from first stage regressions. Our identifying assumption in the IV model is that e-cigarette and traditional cigarette taxes affect demand only through their effects on e-cigarette and traditional cigarette prices. Thus, we assume that there are no other channels though which taxes can influence sales (e.g., signaling of product risk). We acknowledge that assuming no non-price effects is a strong supposition.

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 90,730 UPC-locality-quarter observations, of which 10,130 are subject to an e-cigarette tax. The average e-cigarette price per ml of liquid is $4.40, and the average price is slightly higher in localities that adopt an e-cigarette tax (measured before the tax) than in localities that did not adopt a tax by the end of our timeframe. The conditional (non-zero) mean e-cigarette tax is $0.70 per fluid ml. The unconditional mean is $0.05 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 much smaller in magnitude than ad valorem taxes, with the conditional mean value of unit taxes being $0.17 and ad valorem taxes being $1.11. These differences underscore the importance of accounting for the size of the tax.

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. On average, 1,317 mls of e-cigarette liquid; 80,732 packs of traditional cigarettes; 5,566 cigars; 5,985 ounces of chewing tobacco; and 712 ounces of loose tobacco are purchased within each locality-quarter by every 100,000 residents. For e-cigarettes, purchases are much lower in localities that adopt an e-cigarette tax, and this is true for traditional 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 traditional cigarette indoor smoking bans are much more prevalent (80%).

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 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, 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 larger magnitude of these taxes.

b. Herfindahl–Hirschman Index

Since the pass-through rate of taxes to prices in part depends on market concentration, we provide supportive evidence by calculating the sample Herfindahl–Hirschman Index (HHI). We use 100% of the e-cigarette products identified in the NRSD[12] to calculate a unit-specific HHI for 81 unique e-cigarette brands[13] in the NRSD between 2011 and 2017. The annual HHI values are 0.294 (2011), 0.357 (2012 and 2013), 0.215 (2014), 0.154 (2015), 0.162 (2016), and 0.175 (2017). The mean HHI over the full time period is 0.245 and this has declined by 40% between 2011 and 2017. An HHI value of over 0.25 is classified as a highly concentrated industry and an HHI value

[12] Nielsen began to categorize specific UPC codes as e-cigarettes in 2013. We identify e-cigarettes in 2011 and 2012 as those categorized by Nielsen as e-cigarettes in 2013 and after. For our calculation of the HHI we use all e-cigarettes categorized by Nielsen rather than the 94.5% matched to additional characteristics.

[13] We group obvious brands produced by the same company together. For example, BLU is listed as 'BLU CIGS,' 'BLU ECIGS,' 'BLU ECIGS PLUS+,' etc.

between 0.15 and 0.25 is a moderately concentrated industry (U.S. Department of Justice 2010). In retail settings, e-cigarettes have been therefore sold in a highly concentrated industry from 2011 to 2013, and have been sold in a moderate to highly concentrated industry from 2014 to 2017. This finding suggests an imperfect level of market competition, which is highly relevant to our main results, as imperfect competition has been theoretically linked to over-shifting of taxes to prices (Besley and Rosen 1999).[14]

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 independent 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, then we add locality and quarter fixed effects, then we add time-varying controls, then finally we replace the locality fixed effects with UPC-by-locality fixed effects in the last column.[15] We find that every $1.00 increase in e-cigarette taxes raises e-cigarette prices by over $1.26 in all regressions and over $1.51 in the specifications with fixed effects. These estimates are all statistically significantly different from zero (and from one) at the 5% level. We therefore find robust evidence that e-cigarette taxes are over-shifted to consumers. Examining the last two columns, we do not see that changes in traditional cigarette taxes lead to statistically significant changes in e-cigarette prices, and the coefficient estimates are small in magnitude.

[14] 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. 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. While such a story seems plausible in the case of e-cigarette taxes since traditional cigarettes are a potential substitute, a necessary component is that e-cigarette taxes increase traditional cigarette prices, and we do not observe this pattern in the data (see Appendix Table 4).

[15] In a model with just locality and quarter fixed effects, the within R-squared is 0.0162, between R-squared is 0.0089, and overall R-squared is 0.0168.

Our 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, for example, alcohol, traditional cigarettes, 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 1.5. A number of possible mechanisms for a higher than 100% pass-through rate exist within the e-cigarette market. For example, our HHI 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. How best to specify an event-study in our study is not immediately clear, as our situation presents a number of challenges. First, our treatment is a continuous treatment, instead of a binary variable, and some of these ‘treatments’ represent decreases in tax rates. Relatedly, some localities have multiple treatment changes within our study period. Third, there may be anticipatory changes by consumers in the quarters before a tax change, making the usual event-study setup of omitting the period immediately prior to treatment, difficult.

We take two approaches to specifying an event-study model to address these challenges. 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 (that is we ignore any post-tax changes either due to inflation or due to future tax changes and consider the extensive margin of taxation). We then construct 16 quarter leads (i.e., interactions between an indicator variable for being a tax adopting states and the time-to-event) and four quarter lags around this event. Periods (quarter-years) more than 16 (four) quarters in advance (after) the effective date are included in the -16 (+4) bin. 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.

Second, we follow an approach developed by Cotti, Nesson, and Tefft (2018) in a study of traditional cigarette taxes, which is also similar to event-study models reported in Allcott and Rafkin (2020). Cotti, Nesson, and Tefft (2018) examine, as we do, 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 Q2 2013 and Q3 2013, the e-cigarette tax nominal changes that occur 16 periods in the future in this state are \$0.55 and \$0.78 respectively. The \$0.55 change is attributable to the state's initial tax of \$0.55 effective Q2 2017 and the second change is attributable to the legislated tax increase from \$0.55 to \$1.33 effective Q3 2017. All non-adopting localities are coded as zero for event-time bins. The omitted category is the period (quarter-year) ≥16 quarters prior to the event.

Figures 2 and 3 shows the results, displaying the dynamics of e-cigarette prices in the quarters before and after an e-cigarette tax increase. Figure 2 uses event-time bins indicating the effective date of any e-cigarette tax, whereas Figure 3 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 0.3 and 0.5, suggesting that the *implementation* of an e-cigarette tax (without consideration of the tax magnitude) raises prices by $0.30 to $0.50, on average. When considering the size of the e-cigarette tax change in Figure 3, the coefficient increases from $1.46 in the quarter after the tax increase to over $2.48 in the final event-time bin one year and more after the tax change.

We also test the robustness of our results in a number of ways. Table 4 lists results from a number of specification tests. We exclude U.S. Census divisions[16] that do not include any localities with an e-cigarette tax by the end of our study period, include U.S. Census division-by-quarter fixed effects, include UPC-by-quarter fixed effects, use different weighting methodologies, examine an alternative strategy for constructing the e-cigarette tax variable (see the Appendix for tax variable construction details), estimate models for which we impute e-cigarette prices when no sale occurred in that locality-by-quarter[17] using the last available price, and first exclude the period of e-cigarette tax enactment and second control for this period. Our results remain broadly stable and coefficient estimates suggest an over-shifting of e-cigarette taxes to prices in all specifications.

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

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

[17] E-cigarette prices may be missing for three reasons: (1) the product has not yet been introduced into that locality, (2) the product has been introduced in that locality but not sold in that particular quarter, or (3) the product has been discontinued in that locality. Observations from scenario (1) are not relevant to pass-through estimates and therefore are appropriately not included in the analysis. Observations from (2) and (3) could be important in estimating pass-through if the tax passes through at such a high rate that it causes products to not be purchased in that quarter (scenario 2), or ever again (scenario 3). Our results are virtually unchanged when using the last available price, thus helping to alleviate these concerns.

to be equated as unit taxes. Finally, Anderson, De Palma, and Kreider (2001) show that ad valorem taxes may induce lower pass-through than unit taxes under imperfect competition. To address these issues, we estimate separate regression models that use (i) state-level variation in taxes (i.e., drop treated counties within states) and (ii) 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. We bootstrapped the difference in the coefficient estimates using a parametric bootstrap (500 repetitions). The difference is statistically significant at the 1% level. We next exclude California, Minnesota, Pennsylvania, and Montgomery County Maryland; that is the localities for which we assume the wholesale price is identical to the wholesale price in DC when we transform the ad valorem tax to a unit tax. The purpose of this exercise is to assess whether our conversion procedure (see the Appendix) drives our findings. Results after excluding the above-noted localities are stable (Table 4). We also lag the e-cigarette tax variable by one quarter and one year to allow for dynamic effects (Table 4). Finally, we drop years prior to 2013, i.e., the time period prior to Nielsen adding a specific UPC category for e-cigarettes, from the analysis sample.

Next, we systematically drop treatment localities to examine whether any single treated locality has an outsized impact on our coefficients. These results, shown in Appendix Table 2, suggest that our results are stable when removing individual treatment localities. Finally, in Appendix Table 3, we aggregate the data to the locality-by-quarter level to examine pass-through rate at a higher level of aggregation that does not hold constant product availability/quality. This specification also allows us to examine whether e-cigarette taxes lead to changes in e-cigarette products and/or characteristics. To this end, we examine whether e-cigarette taxes are related to the number of new e-cigarette products in each quarter and locality and whether they are related to the average ounces of liquid per unit sold or nicotine concentration. In this case, we find a somewhat smaller pass-through rate estimate ($1.19), but the 95% confidence interval includes our estimate from Table 3. We do not find that e-cigarette taxes led to changes in the number of e-cigarette products sold for the first time in a given locality, in the liquid per unit sold, or in nicotine concentration, suggesting that manufacturers are not changing their offering of products nor that consumers are exhibiting compensatory purchasing behaviors in response to tax changes.

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. Of note, we are unaware of any other factor or policy that followed the same staggered rollout across U.S. localities as the e-cigarette taxes that we study. We report our placebo testing in Appendix Figure 1. Our main coefficient estimate (reported with a dark diamond) is an outlier, suggesting a true relationship is present.

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

Next, we examine the effects of e-cigarette and traditional cigarette prices on the sales of e-cigarettes and other tobacco products. For these analyses, we examine sales at the locality-by-quarter level with equation (3), an IV regression where we instrument for e-cigarette prices and traditional cigarette prices with e-cigarette taxes and traditional cigarette taxes. Relative to the reduced form models estimated thus far, these IV analyses require the additional assumption that taxes only influence sales via prices (i.e., the exclusion restriction). We cannot rule out the possibility that taxes could exert part of their influence through mechanisms besides prices, such as signaling about health risks, in which case the IV estimates could be overstated.

Table 5 shows the results of these models across e-cigarettes and traditional cigarettes. In the first column, every $1.00 increase in e-cigarette prices reduces e-cigarette sales by 356 ml of liquid, the coefficient estimate is statistically significant at the 5% level. The e-cigarette results provide an estimated price elasticity of demand for e-cigarettes of -1.3.[18] This estimate suggests that a 10% increase in e-cigarette prices leads to a 13% decrease in e-cigarette sales. Note that, since the magnitude of the estimate is greater than one, we consider it unlikely that our finding that e-cigarettes are price elastic can be attributed to the potential presence of secondary mechanisms besides price (e.g. signaling of health risks) noted above.

We also find that e-cigarettes and traditional cigarettes are economic substitutes, evident in the positive and statistically significant effect of e-cigarette prices on traditional cigarette sales (and vice versa). In particular, a 1% increase in the price of traditional cigarettes increases e-cigarette sales by 1.4%, while a 1% increase in the price of e-cigarettes increases traditional cigarette sales by 0.8%.[19] Given that the traditional cigarette market remains much larger in size than the e-cigarette market, the larger cross-product effects of traditional cigarette prices are perhaps not surprising. We estimate a traditional cigarette own price elasticity of -0.8, which is in line with many previous estimates of the price elasticity of demand for traditional cigarettes.[20]

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[18] We multiply the coefficient from Table 5 by the average year-prior pre-tax e-cigarette price (4.48 from Appendix Table 3) and divide by average year-prior pre-tax e-cigarette sales (1,236 from Table 5): -356* (4.48/1,236) = -1.3.

[19] Here, we take the traditional cigarette price coefficient from the first column of Table 5 multiplied by the average year-prior pre-tax cigarette price (5.87 from Appendix Table 3) and divide by the average e-cigarette sales in the year prior to the first cigarette tax (1,150 from Table 5). 275*(5.87/1,150) = 1.4. The second number is calculated in a similar way, except we use the average year-prior pre-tax e-cigarette price (4.48 from Appendix Table 3) and the average cigarette sales in the year prior to the e-cigarette tax (56,438 from Table 5). Thus, 10,260*(4.48/56,438) = 0.8.

[20] Here, -9,095*(5.87/69,111) = -0.77

Comparable elasticities can be computed using back-of-the-envelope calculations based on reduced-form regressions of the sales of tobacco products on traditional cigarette and e-cigarette taxes using equation (2). Appendix Table 4 shows results from these specifications. We find that every $1.00 increase in e-cigarette taxes reduces e-cigarette sales by -449 ml and increases traditional cigarette sales by 12,808 traditional cigarettes. These coefficient estimates translate into own and cross-price elasticities of -1.47 and 0.86, respectively, which are very similar to the own and cross-price elasticities we estimate from Table 5. The own and cross-price elasticities estimated from traditional cigarette taxes are -0.71 and 0.86, which are again very similar to the elasticities calculated from Table 5.

We show event studies for the reduced form model in Figure 4. E-cigarette sales are broadly stable in the periods before an e-cigarette tax change with the exception of a temporary decline in e-cigarette sales three quarters before the tax change (which would bias the downward effect of an e-cigarette tax towards the null of no effect). After a tax increase, e-cigarette sales decrease steadily over the next four quarters. Trends in traditional cigarettes are also broadly stable in the periods before an e-cigarette tax change. However, in the quarter before the tax, sales markedly increase. After the e-cigarette tax change, traditional cigarette sales increase to a higher level than before the tax, providing further evidence that e-cigarettes and traditional cigarettes are substitutes.

Next, we re-estimate our IV 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 Appendix Table 5 suggest that our results are stable when removing individual treatment localities.[21]

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[21] According to NRSD documentation and our conversation with data administrators, in 2017 the composition of stores tracked within the NRSD shifted from grocery stores to dollar stores and club stores. We also explore the sensitivity of our estimates to dropping 2017 data that incorporated this compositional shift. Coefficient estimates remained of the same sign and were not statistically different from estimates using 2017 data.

In Table 6 we estimate the effect of e-cigarette prices separately on flavored and non-flavored e-cigarettes, and traditional cigarettes (i.e., we use the IV model outlined in equation (3)). Age is strongly predictive of e-cigarette flavor use, thus studying the effect of e-cigarette prices on sales of flavored e-cigarettes could indicate possible heterogeneity in price responsiveness by age. According to the 2014-15 Population Assessment of Tobacco and Health (PATH) data, 74% of adults ≥25 years of age 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). Coefficient estimates suggest e-cigarette price increases have the largest impact on flavored e-cigarette sales, with a $1.00 increase in e-cigarette prices reducing flavored e-cigarettes sales roughly 41% of the year-prior pre-tax mean compared to 26% of the mean for menthol/mint e-cigarettes and 23% of the mean for non-flavored e-cigarettes. Higher e-cigarette prices increase non-flavored traditional cigarette sales by 17% and mentholated traditional cigarette sales by 22%. Taken together, these results suggest that higher e-cigarette prices (which we are instrumenting with taxes) may disproportionately impact young people and cause out-sized substitution from flavored e-cigarette products towards mentholated traditional cigarettes (i.e., the only remaining legally available flavor of cigarettes). Reduced form results are reported in Appendix Table 6 and confirm this pattern.

Finally, we explore the effect of taxes and prices on sales of other tobacco products: cigars, chewing tobacco, and loose tobacco. Results are listed in Table 7 (IV results) and Appendix Table 7 (reduced form results). We do not find any statistically or economically significant effects of price changes or tax changes on the sales of the other categories of tobacco products.

6. Conclusion

In this paper, we examine the effects of e-cigarette taxes on e-cigarette prices, purchases, and other tobacco-related outcomes. We use UPC-level data on retail sales of e-cigarettes and other tobacco products from the NRSD. Importantly, we link the vast majority of e-cigarette UPCs (94.5%) in the NRSD to supplemental product characteristics collected by our research team, specifically the liquid quantity and flavors.

We find that e-cigarette taxes are passed through to e-cigarette prices at a rate greater than 100%, with is more likely in a market with high concentration as suggested by our HHI calculation. Our pass-through rate estimate is similar to an estimate from the literature for the state of Minnesota (Saffer et al. 2020). We note that our 95% confidence interval includes values from 1.2 to 1.9. The width of this interval allows us to rule out, with 95% confidence, a one-to-one pass through rate. Further, the lower tail of this confidence interval is very similar to estimates of the traditional cigarette pass-through rate. For example, Viscusi and Hersch (2010) estimate a pass-through rate of 1.2. We also provide the first estimates of retail-based e-cigarette market concentration, calculating an HHI of 0.245, which indicates a moderately to highly concentrated market as classified by the U.S. Department of Justice (U.S. Department of Justice 2010).

We also find that e-cigarettes are an elastic good, with an estimated price elasticity of demand of -1.3. We estimate that e-cigarettes and traditional cigarettes are economic substitutes, as e-cigarette sales increase with traditional cigarette price/tax increases and traditional cigarette sales increase with e-cigarette price/tax increases.

A limitation of our study is the reliance on e-cigarettes sold through retail stores, thus 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 reason why individuals would have a financial incentive to change the type of store where they shop in response to an e-cigarette tax.[22] Moreover, analysis of survey data on adult e-cigarette and traditional cigarette use without regard to purchase location (Pesko, Courtemanche, and Maclean 2020), and administrative and survey data for pregnant women (Abouk et al. 2020) provide same signed coefficient estimates on e-cigarette taxes, which supports our results. Our finding that flavored e-cigarettes are disproportionately impacted by taxes is also in line with evidence elsewhere suggesting young people are more price responsive in terms of tobacco product purchasing (Chaloupka and Warner 2000).

Between the end of our study period (December 2017) and March 15, 2020, 15 additional states enacted new e-cigarette laws: Connecticut, Delaware, Illinois, Maine, Massachusetts, Nevada, New Hampshire, New Jersey, New Mexico, New York, Ohio, Vermont, Washington, Wisconsin, and Wyoming (Public Health Law Center 2020). In late February, 2020, the U.S. House of Representatives approved a national e-cigarette tax proportional to the federal traditional cigarette tax (House Bill 2339 2020). Additionally, in 2019 eight states imposed temporary bans on the sale of all e-cigarettes or flavored e-cigarettes (Campaign for Tobacco-Free Kids 2019a),

[22] 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 Nielsen 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 additionally do the same for online and 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 helps us conclude that our model estimates are not substantially impacted by varying levels of data availability by retail channel.

which is equivalent to an infinite price increase for the banned products, absent likely black market activity.

Our study suggests that, as intended, e-cigarette taxes raise e-cigarette prices and reduce e-cigarette sales. However, an unintended effect is an increase in traditional cigarette sales. The current House bill specifies a tax rate of $50.33 per 1,810 milligrams of nicotine (or $0.028 per milligram). JUUL pods today contain 59 milligrams/ml (at 5% nicotine volume). Assuming this conversion, we simulate that if this bill were to become law, the tax could raise e-cigarette prices by $2.48 per ml ($0.0278 x 59 x 1.51 from Table 3). While this estimate is simply a response estimated from an average treatment effect, such a price increase could reduce e-cigarette purchases by 883 ml per 100,000 adults ($2.48 x 356 from Table 5). Further, while difficult to infer the exact scope of the response from a single coefficient estimate, our estimates do strongly indicate this large e-cigarette tax would notably increase traditional cigarette purchases.

Our finding of a notable substitution response may be explained by several factors. First, while e-cigarettes have small market share, they appear to be a widely disruptive product for the traditional cigarette industry which could explain why Philip Morris expects cigarettes to disappear in some countries within the next 10 to 15 years (Lester 2020). Second, e-cigarettes have been found using a randomized control trial in England to be twice as effective as existing nicotine replacement therapy (NRT) in achieving one-year traditional cigarette abstinence:18.0% versus 9.9% (Hajek et al. 2019). This finding is despite the fact that the nicotine content of e-cigarettes sold in England is capped at no more than 20 milligrams/ml (CNN 2019), which is approximately one third of the JUUL nicotine strength of 59 milligrams/ml (at 5% nicotine). American e-cigarettes contain more nicotine and they may therefore be more effective smoking cessation products than even the high success rate found in England. Third, e-cigarettes are more widely used for smoking cessation than NRT, with one study finding that 32% of current and past-year former smokers used e-cigarettes as their single method to quit smoking, compared to 18% using an NRT (Rodu and Plurphanswat 2017). The combination of e-cigarettes having a relatively small market share and their effectiveness and popularity in quitting smoking contributes to the large substitution effects that we estimate. In sum, our results suggest that e-cigarettes are useful smoking cessation products.

Although vaping-related illnesses are a public health concern, traditional 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 traditional cigarettes. Thus, balancing e-cigarette and traditional cigarette use will continue to be an important issue for policymakers to consider as they develop e-cigarette related tobacco control policies.

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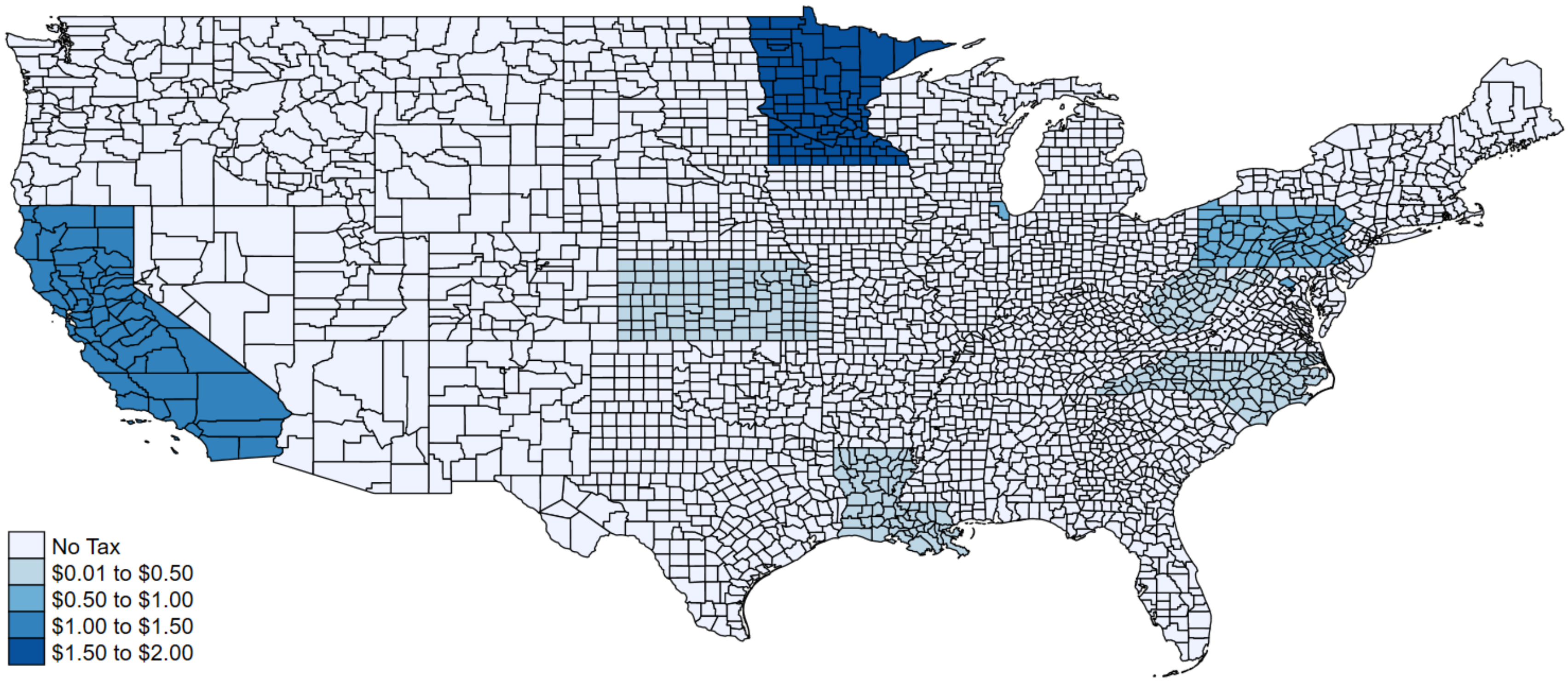
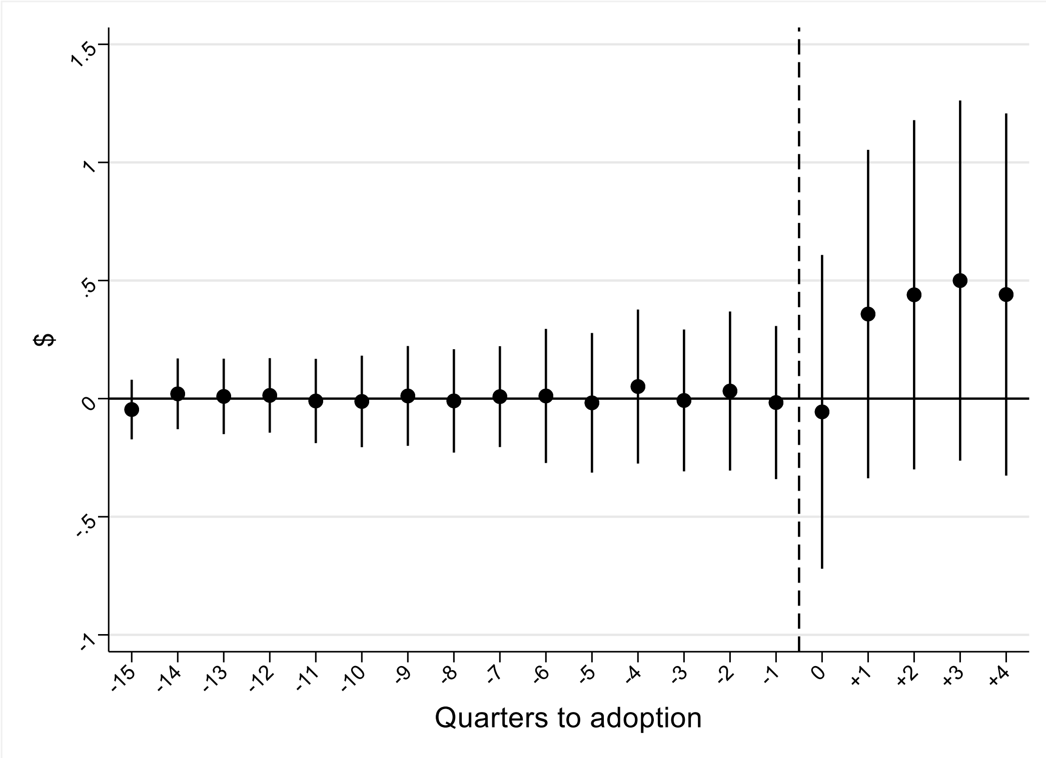
Figure 1. Map of e-cigarette taxes per ml of vaping liquid in 4Q 2017



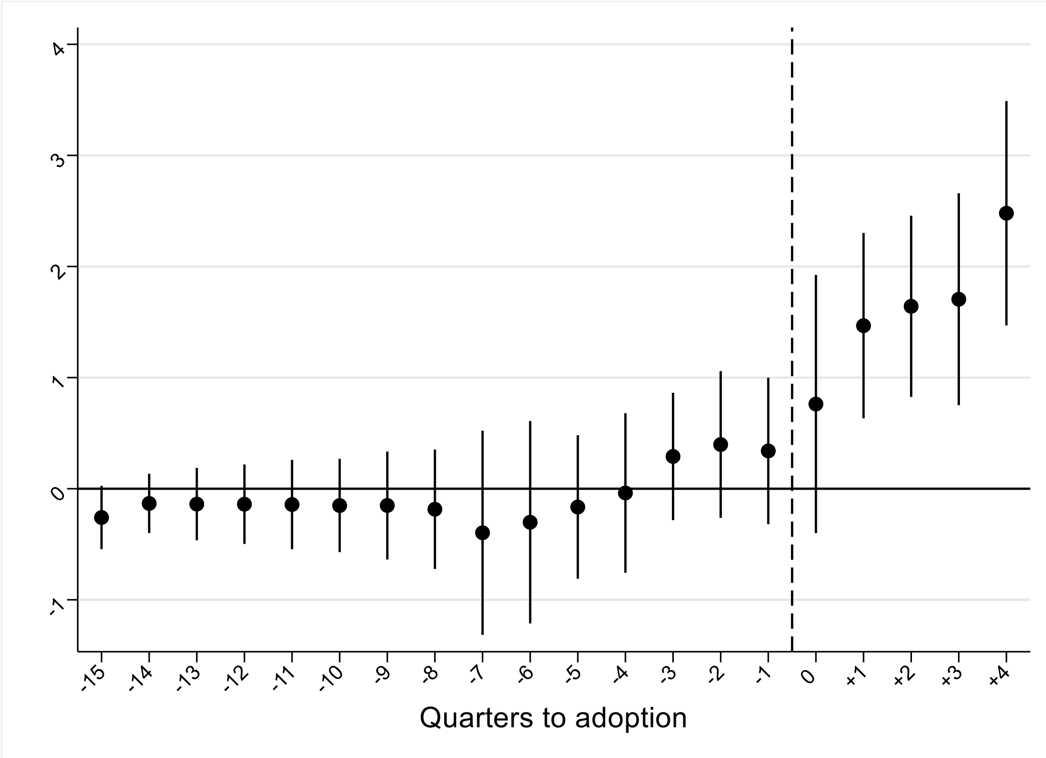
Notes: See text for details.

Figure 2. Effect of e-cigarette taxes on e-cigarette prices using an event-study: Nielsen retail sales UPC-level data 2011-2017



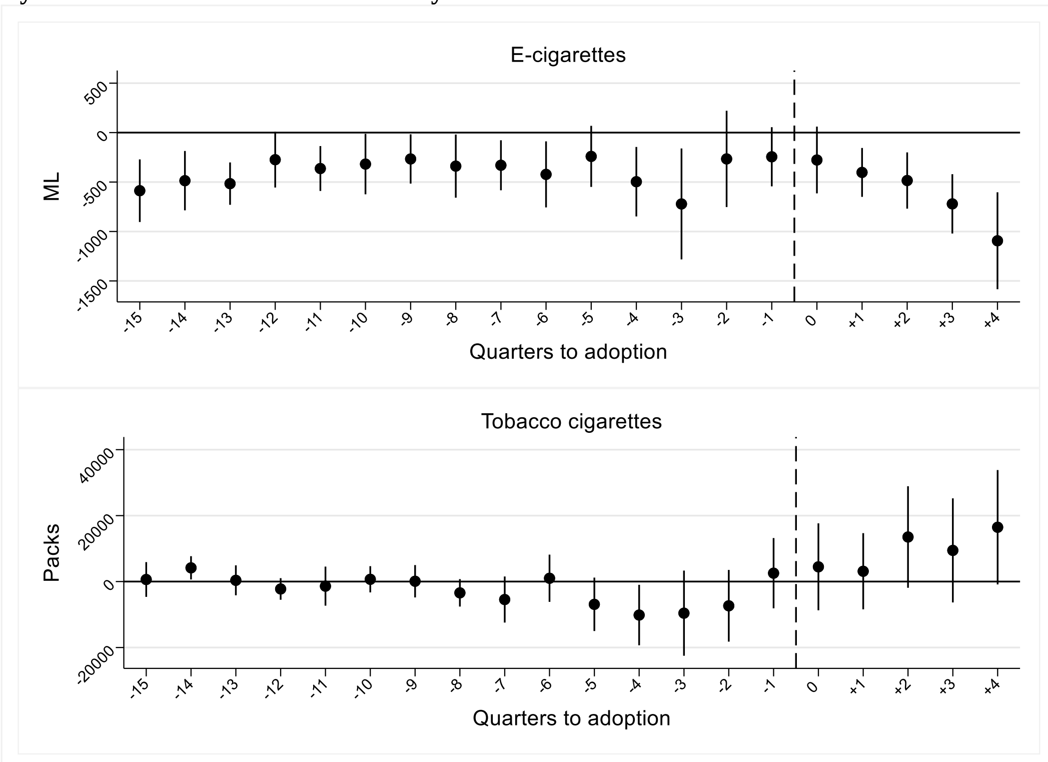
Notes: The unit of observation is a UPC-code in a locality (state or county) in a quarter (quarter-by-year). The model is estimated by equation (1) except using lag and lead indicators from the first available e-cigarette tax in a given locality. The model is estimated with least squares and controls for time-varying locality characteristics, UPC-by-locality fixed effects, and period (quarter-by-year) fixed effects. Circles reflect the coefficient estimate and vertical solid lines reflect 95% confidence intervals. The omitted category is ≥16 quarters prior to policy adoption.

Figure 3. Effect of e-cigarette taxes on e-cigarette prices using a Cotti et al (2018) event-study-style model: Nielsen 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. 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.

Figure 4. Effect of e-cigarette taxes on e-cigarette and cigarette sales using a Cotti et al (2018) event-study-style model: Nielsen 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. 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.

Table 1. Summary statistics: Nielsen 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)	4.40	4.50	4.34
E-cigarette taxes			
E-cigarette standardized tax ($)	0.05	--	--
Conditional e-cigarette standardized tax ($)	0.70	--	--
Conditional e-cigarette standardized tax ($) – unit	0.17	--	--
Conditional e-cigarette standardized tax ($) – ad valorem	1.11	--	--
Policies and Demographics			
Traditional cigarette tax ($)	1.57	1.19	1.60
% covered by indoor vaping ban	0.14	0.09	0.13
% covered by indoor smoking ban	0.81	0.86	0.79
Border a locality with a e-cigarette tax	0.21	0.01	0.23
Vape-free public K-12 schools	0.11	0.01	0.13
Smoke-free public K-12 schools	0.37	0.29	0.38
Tobacco 21 law	0.01	0.02	0
Beer tax ($)	0.26	0.19	0.28
ACA Medicaid expansion	0.34	0.29	0.33
Unemployment rate	6.00	7.14	5.91
Age	38.4	38.1	38.4
Male	0.49	0.48	0.49
Female	0.51	0.52	0.51
White	0.80	0.76	0.82
African American	0.12	0.16	0.11
Other race	0.08	0.08	0.08
Hispanic	0.11	0.12	0.12
Born outside the U.S.	0.10	0.12	0.10
Less than high school	0.15	0.16	0.15
High school	0.29	0.29	0.29
Some college	0.27	0.25	0.28
College	0.28	0.29	0.28
Population (millions)	6.43	10.2	5.85
Observations	90730	10130	73693

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.

Table 2. Summary statistics: Nielsen 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)	1,317	899	1,439
Traditional cigarette (packs)	80,732	59,357	88,508
Non-flavored e-cigarettes (ml)	614	433	675
Menthol e-cigarettes (ml)	397	276	434
Flavored e-cigarettes (ml)	305	189	327
Non-flavored traditional cigarettes (packs)	59,825	42,860	65,860
Menthol traditional cigarettes (packs)	20,907	16,497	22,648
Cigar (units)	5,566	3,362	6,119
Chewing tobacco (ounces)	5,985	5,959	5,894
Loose tobacco (ounces)	712	593	723
E-cigarette and traditional cigarette prices			
E-cigarette price ($)	4.69	4.79	4.60
Traditional cigarette price ($)	6.20	5.73	6.25
E-cigarette taxes			
E-cigarette standardized tax ($)	0.05	--	--
Conditional e-cigarette standardized tax ($)	0.74	--	--
Conditional e-cigarette standardized tax ($) - ad valorem	0.16	--	--
Conditional e-cigarette standardized tax ($) - unit	1.10	--	--
Policies and demographics			
Traditional cigarette tax ($)	1.64	1.04	1.77
% covered by indoor vaping ban	0.14	0.14	0.12
% covered by indoor smoking ban	0.80	0.86	0.77
Border a locality with a e-cigarette tax	0.18	0.0004	0.23
Vape-free public K-12 schools	0.10	0.02	0.11
Smoke-free public K-12 schools	0.31	0.20	0.33
Tobacco 21 law	0.03	0.07	0
Beer tax ($)	0.26	0.19	0.28
ACA Medicaid expansion	0.34	0.38	0.30
Unemployment rate	6.45	7.75	6.24
Age	38.2	37.6	38.3
Male	0.49	0.49	0.49
Female	0.51	0.51	0.51
White	0.78	0.76	0.79
African American	0.13	0.11	0.13
Other race	0.09	0.13	0.076
Hispanic	0.17	0.25	0.16
Born outside the U.S.	0.14	0.19	0.13
Less than high school	0.16	0.18	0.16
High school	0.28	0.27	0.29
Some college	0.27	0.27	0.27
College	0.28	0.28	0.28
Population (millions)	14.0	25.0	11.0
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.

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

Outcome:	**E-cigarette price ($)**			
E-cigarette standardized tax ($)	1.256*** [1.064,1.449]	1.508*** [1.119,1.898]	1.518*** [1.175,1.860]	1.488*** [1.287,1.688]
Traditional cigarette tax per pack ($)	--	--	0.020 [-0.136,0.175]	0.058 [-0.188,0.303]
Locality fixed effects	N	Y	Y	n/a
Period (quarter-by-year) fixed effects	N	Y	Y	Y
Time-varying controls	N	N	Y	Y
UPC-by-locality fixed effects	N	N	N	Y
Observations	90730	90730	90730	90730
Mean: e-cigarette price in e-cigarette tax adopting localities, in the year prior to the tax ($)	3.79	3.79	3.79	3.79

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. 95% confidence intervals that account for within-locality clustering are reported in square brackets. ***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

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

Outcome:	**E-cigarette price ($)**
Mean: e-cigarette tax adopting localities, in the year prior to the tax┼	3.79
Exclude divisions with no adopting localities by 2017 (New England, East South Central, and Mountain)	
E-cigarette standardized tax ($)	1.412***
	[1.234,1.589]
Observations	59475
Include division-by-quarter fixed effects	
E-cigarette standardized tax ($)	1.509***
	[1.331,1.688]
Observations	90730
Include UPC-by-quarter fixed effects	
E-cigarette standardized tax ($)	1.577***
	[1.235,1.920]
Observations	90730
Unweighted	
E-cigarette standardized tax ($)	1.522***
	[1.239,1.805]
Observations	90730
Weight by population	
E-cigarette standardized tax ($)	1.404***
	[1.207,1.600]
Observations	90730
Weight by quarterly e-cigarette sales in 2013	
E-cigarette standardized tax ($)	1.312***
	[1.082,1.541]
Observations	90730
Use alternative e-cigarette tax variable[1]	
E-cigarette standardized tax ($)	1.256***
	[0.799,1.713]
Observations	90730
Impute missing e-cigarette prices[2]	
E-cigarette standardized tax ($)	1.425***
	[1.259,1.592]
Observations	114223
Drop enactment period	
E-cigarette standardized tax ($)	1.587***
	[1.376,1.799]
Observations	88890
Control for the enactment period	
E-cigarette standardized tax ($)	1.474***
	[1.251,1.697]
Enactment period	-0.049
	[-0.261,0.163]
Observations	90730

Table 4. (continued)

Drop treated sub-state localities	
E-cigarette standardized tax ($)	1.618***
	[1.421,1.814]
Observations	87919
Drop treated state localities	
E-cigarette standardized tax ($)	1.059***
	[0.838,1.281]
Observations	76504
Exclude converted ad-valorem tax localities┼	
E-cigarette standardized tax ($)	1.443***
	[1.293,1.593]
Observations	83766
Lag e-cigarette tax one quarter	
E-cigarette standardized tax ($)	1.529***
	[1.290,1.768]
Observations	90647
Lag e-cigarette tax one year	
E-cigarette standardized tax ($)	1.325***
	[0.834,1.816]
Observations	88722
Drop 2011-2012	
E-cigarette standardized tax ($)	1.300***
	[1.128,1.472]
Observations	82923

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. 95% confidence intervals that account for within-locality clustering are reported in square brackets. ┼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.

[1] See the appendix for additional details.

[2] 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.

┼Converted ad valorem tax localities include California, Minnesota, Pennsylvania, and Montgomery County Maryland.

Table 5. Effect of e-cigarette and traditional cigarette prices on sales per 100,000 adults simultaneously instrumenting e-cigarette and traditional cigarette prices with e-cigarette and traditional cigarette taxes: Nielsen state-level sales data 2011-2017

Outcome:	**E-cigarettes**	**Traditional cigarettes**
E-cigarette price ($)	-356**	10,260***
	[-702,-11]	[2,547,17,973]
Traditional cigarette price ($)	275**	-9,095***
	[51,498]	[-13,874,-4,315]
Observations	1428	1428
Mean: e-cigarette tax adopting localities, in the year prior to the tax	1,236	56,468
Mean: traditional cigarette tax adopting localities, in the year prior to the first traditional cigarette tax increase	1,150	69,111

Notes: 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. 1st stage F-statistics are 12.88 for e-cigarette prices and 436.87 for traditional cigarette prices. 95% confidence intervals that account for within-state clustering are reported in square brackets. ***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

Table 6. Effect of e-cigarette and traditional cigarette prices on flavored tobacco product sales per 100,000 adults simultaneously instrumenting e-cigarette and traditional cigarette prices with e-cigarette and traditional cigarette taxes: Nielsen state-level sales data 2011-2017

Outcome:	**Non-flavored e-cigarettes**	**Menthol /mint e-cigarettes**	**Flavored e-cigarettes**	**Non-flavored traditional cigarettes**	**Menthol traditional cigarettes**
E-cigarette price	-119*	-93*	-144*	7,324**	2,936**
($)	[-247,8]	[-193,7]	[-313,25]	[1,232,13,417]	[521,5,351]
Traditional	83*	46	145**	-6,036***	-3,059***
cigarette price ($)	[-4,171]	[-28,120]	[23,267]	[-10,003,-2,069]	[-4,520,-1,597]
Observations	1428	1428	1428	1428	1428
Mean: e-cigarette tax adopting localities, in the year prior to the tax	519	363	351	41,965	14,502
Mean: traditional cigarette tax adopting localities, in the year prior to the first traditional cigarette tax increase	529	346	273	51,246	17,864

Notes: 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. 1st stage *F*-statistics are 12.88 for e-cigarette prices and 436.87 for traditional cigarette prices. 95% confidence intervals that account for within-state clustering are reported in square brackets. ***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

Table 7. Effect of e-cigarette and traditional cigarette prices on cigar, chewing tobacco, and loose tobacco sales per 100,000 adults simultaneously instrumenting e-cigarette and traditional cigarette prices with e-cigarette and traditional cigarette taxes: Nielsen state-level sales data 2011-2017

Outcome:	**Cigars**	**Chewing tobacco**	**Loose tobacco**
E-cigarette price ($)	-633 [-1,797,530]	110 [-1,288,1,508]	-156 [-454,142]
Traditional cigarette price ($)	619 [-417,1,655]	-127 [-1,125,871]	105 [-116,325]
Observations	1428	1428	1428
Mean: e-cigarette tax adopting localities, in the year prior to the tax	4,382	6,279	557
Mean: traditional cigarette tax adopting localities, in the year prior to the first traditional cigarette tax increase	3,994	2,741	555

Notes: 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. 1st stage *F*-statistics are 12.88 for e-cigarette prices and 436.87 for traditional cigarette prices. 95% confidence intervals that account for within-state clustering are reported in square brackets. ***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

APPENDIX

Standardizing the E-cigarette Taxes

Through 2017, e-cigarette taxes have been levied using either specific unit taxes or ad valorem taxes. To standardize e-cigarette taxes levied in different ways into a single measure, we combine policy data on e-cigarette taxes and data from the Nielsen Retail Scanner data. Chicago, Cook County, Kansas, Louisiana, North Carolina, and West Virginia use 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 Alaskan counties also have e-cigarette taxes, but Alaska is not included in the Nielsen retail data and is therefore not included in our standardization exercise. Between the end of our study period in 2018 and the end of 2019, ten additional states enacted new e-cigarette laws (Connecticut, Delaware, Illinois, New Mexico, New Jersey, New York, Ohio, Vermont, Washington, and Wisconsin).

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

$$ad\ valorem\ rate_{st} * 0.044 * \frac{sales\ volume\ in\ retail\ units_{st}}{sales\ volume\ in\ ml\ of\ fluid_{st}} = \frac{tax\ revenue_{st}}{sales\ volume\ in\ ml\ of\ fluid_{st}} = tax\ per\ ml\ of\ fluid_{st}$$

Where *s* indexes a tax jurisdiction *s* on a year-by-quarter basis *t*. Tax jurisdictions are defined as 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.

Washington DC's e-cigarette ad valorem tax is benchmarked to be equal to the value of the traditional cigarette unit tax (as determined by DC's tax authority, using a weighted average of all e-cigarette products) (Public Health Law Center 2020). From the 4th quarter of 2015 to the 3rd quarter of 2016, the traditional cigarette tax was \$2.91 per pack in DC and the e-cigarette ad valorem tax (as a percent of the wholesale price) was 67%. Therefore, a 67% ad valorem tax equals \$2.91, and the e-cigarette wholesale price (inclusive of the tax) in DC is equal to \$4.34 (\$2.91 / 67).[23] The taxes were readjusted starting in the 4th quarter of 2016 to the end of 2017, for a ratio of \$4.49 (\$2.92 / 65). On average across these 9 quarters the wholesale price in DC is \$4.44, so we apply that conversion factor nationally and assume that each 1% of ad valorem tax has a value of approximately \$0.044. We multiply the ad valorem rate (e.g. 40, 65, 95) by 0.044 for all ad valorem localities.[24]

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[23] This is somewhat larger than the wholesale price estimate (inclusive of the tax) of \$3.52 for replacement pods in Minnesota in 2012 estimated by Saffer et al. (2020). This difference could reflect wholesale prices being larger in 2017 than in 2012, wholesale prices being larger in Minnesota than in Washington DC, or wholesale prices for replacement pods being different than for a broader array of e-cigarette products. To the extent that wholesale prices change nationally over time, or that wholesale prices exhibit time-invariant differences across localities, our identification strategy using year and county fixed effects removes this as a potential source of bias.

[24] In 2017, CA also equalized their e-cigarette tax with the cigarette excise tax and we find a similar average wholesale price there of \$4.41 per pack in the 3rd and 4th quarter of 2017, which is similar to the average wholesale

Next, we multiply by total sales volume in retail units to obtain overall tax revenue for each tax jurisdiction *s* on a year-by-quarter basis *t*. Sales units include all disposable e-cigarettes, starter kits, and replacement pods in the Nielsen data, after omitting products for which fluid amounts or container amounts could not be identified using internet search and visits to retailers. E-cigarette product characteristics were identified for 94.5% of sales-weighted e-cigarette units as identified by the Nielsen data.

Lastly, we divide total volume in ml of fluid for each tax jurisdiction *s* on a year-by-quarter basis *t*, again after omitting products for which fluid amounts or container amounts could not be identified using internet search and visits to retailers.

One concern with our conversion is that the ratio of sales volume in units to ml of fluid may be endogenous to the e-cigarette tax adoption. Therefore, our primary standardized tax measure uses the ratio for all locations that have not adopted e-cigarette taxes by January 2020. As a sensitivity analysis, we use the ratio specific to each tax jurisdiction. Results are similar regardless of which measure is used.

For Cook County, we do not have the ability to separate Chicago from the rest of Cook County in the Nielsen 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). We, therefore, calculate tax per ml of fluid in the following way:

$$0.55 + \frac{sales\ volume\ in\ containers_{st}}{sales\ volume\ in\ ml\ of\ fluid_{st}} * 0.80 = tax\ per\ ml\ of\ fluid_{st}$$

For the Cook County tax, similar to the approach mentioned earlier to address potential concerns of endogeneity, we used the ratio of sales volume in containers to sale volume in ml of fluid for all locations that have not adopted e-cigarette taxes by January 2020 for our primary standardized e-cigarette tax measure. As a sensitivity analysis, we use the ratio specific to Chicago. Results are similar regardless of which measure is used.

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 added in whole to the weighted tax from Chicago.

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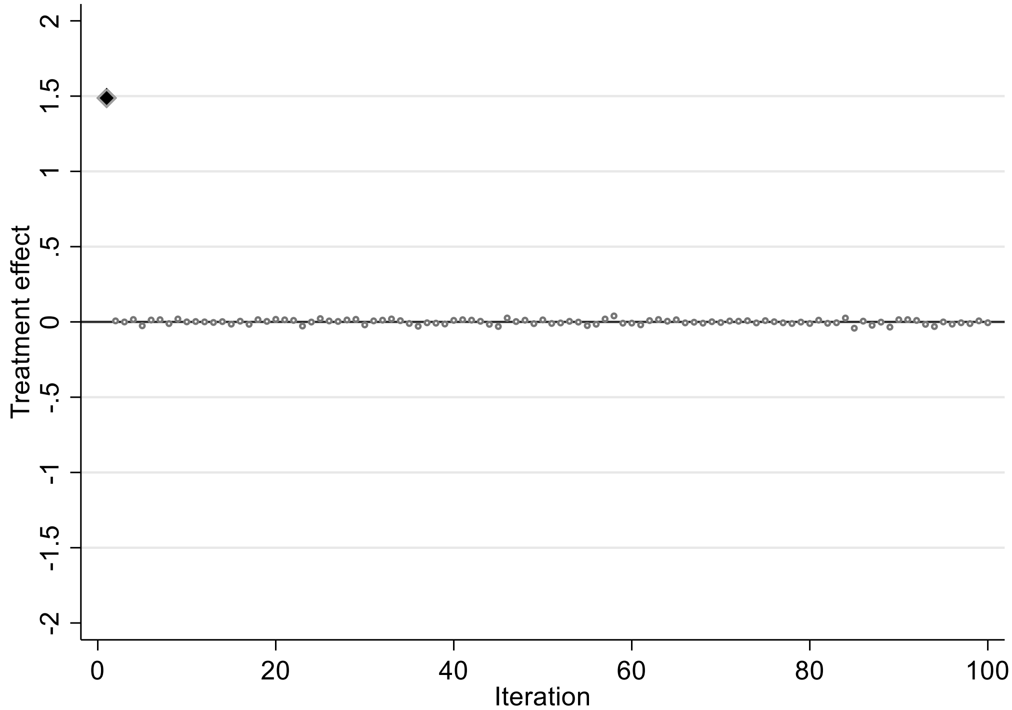
price for DC of $4.44. We use just the average estimated DC wholesale price to convert all ad valorem taxes to excise tax equivalents since this average wholesale price is the earliest available estimate.

Appendix Figure 1. Effect of e-cigarette taxes on e-cigarette prices using an placebo test: Nielsen 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. 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.

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

Locality	Effective date	Unit taxed	Tax amount	Tax value Q4 2017 ($)
State				
California	4/2017, 7/2017	Wholesale price	27.3%, 65.1%	1.272
District of Columbia	10/2015, 10/2016	Wholesale price	67%, 65%	1.272
Kansas	1/2017, 7/2017	Per fluid milliliter	$0.20, $0.05	0.050
Louisiana	7/2015	Per fluid milliliter	$0.05	0.050
Minnesota	8/2010, 7/2013	Wholesale price	35%, 95%	1.849
North Carolina	6/2015	Per fluid milliliter	$0.05	0.050
Pennsylvania	7/2016	Wholesale price	40%	0.775
West Virginia	7/2016	Per fluid milliliter	$0.075	0.075
County/City				
Chicago, Illinois	1/2016	Per unit / per fluid milliliter	$0.80 / $0.55	0.606^
Cook County, Illinois	5/2016	Per fluid milliliter	$0.20	0.606^
Montgomery County, Maryland	8/2015	Wholesale price	30%	0.586

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.

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: Nielsen retail sales UPC-level data 2011-2017

Outcome:	**E-cigarette price ($)**
Mean: e-cigarette tax adopting localities, in the year prior to the tax┼┼	3.79
Exclude California	
E-cigarette standardized tax ($)	1.482*** [1.257,1.706]
Observations	88559
Exclude Cook County, IL	
E-cigarette standardized tax ($)	1.538*** [1.333,1.742]
Observations	89182
Exclude Washington DC	
E-cigarette standardized tax ($)	1.428*** [1.139,1.718]
Observations	89651
Exclude Kansas	
E-cigarette standardized tax ($)	1.493*** [1.291,1.694]
Observations	89155
Exclude Louisiana	
E-cigarette standardized tax ($)	1.476*** [1.278,1.674]
Observations	88729
Exclude Minnesota	
E-cigarette standardized tax ($)	1.399*** [1.223,1.576]
Observations	89263
Exclude Montgomery County, MD	
E-cigarette standardized tax ($)	1.551*** [1.355,1.746]
Observations	89467
Exclude North Carolina	
E-cigarette standardized tax ($)	1.490*** [1.289,1.690]
Observations	88656
Exclude Pennsylvania	
E-cigarette standardized tax ($)	1.528*** [1.304,1.752]
Observations	88667
Exclude West Virginia	
E-cigarette standardized tax ($)	1.484*** [1.284,1.684]
Observations	88934

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. 95% confidence intervals that account for within-locality clustering are reported in square brackets. ┼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.

Appendix Table 3. Effect of e-cigarette and traditional cigarette taxes on the prices, number of new e-cigarette products, and liquid per unit using a two-way fixed effects model: Nielsen retail sales state-level data 2011-2017

Outcome:	**Traditional cigarette price ($)**	**E-cigarette price ($)**	**Number of new e-cigarette products**	**Liquid per unit**	**Nicotine % of liquid amount**
E-cigarette standardized tax ($)	0.109 [-0.090,0.308]	1.188** [0.212,2.163]	-2.132 [-5.788,1.523]	-0.007 [-0.224,0.210]	0.086 [-0.067,0.239]
Traditional cigarette tax per pack ($)	1.071*** [0.970,1.173]	0.038 [-0.416,0.492]	-0.492 [-2.098,1.115]	0.057 [-0.109,0.224]	0.049 [-0.070,0.168]
Observations	1428	1428	1428	1428	1428
Mean: e-cigarette tax adopting localities, in the year prior to the tax	5.97	4.48	18.82	1.40	2.69
Mean: traditional cigarette tax adopting localities, in the year prior to the first traditional cigarette tax increase	5.87	4.70	17.19	1.34	2.51

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 average quarterly traditional cigarette sales in 2011 in the traditional cigarette pass-through regression; by the average quarterly e-cigarette sales in 2013 in the e-cigarette pass-through regression; and the average quarterly e-cigarette sales in 2013 for the new product, liquid per unit, and nicotine % of liquid amount regressions. 95% confidence intervals that account for within-locality clustering are reported in square brackets. ***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

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

Outcome:	**E-cigarettes**	**Traditional cigarettes**
E-cigarette standardized tax ($)	-449***	12,808**
	[-774,-124]	[3,170,22,446]
Traditional cigarette tax per pack ($)	265***	-8,914***
	[102,428]	[-15,544,-2,283]
Observations	1428	1428
Mean: e-cigarette tax adopting localities, in the year prior to the tax	1,236	56,468
Mean: traditional cigarette tax adopting localities, in the year prior to the first traditional cigarette tax increase	1,150	69,111

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. 95% confidence intervals that account for within-locality clustering are reported in square brackets. ***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

Appendix Table 5. Effect of e-cigarette and traditional cigarette prices on sales per 100,000 adults instrumenting the e-cigarette price with the e-cigarette tax and instrumenting the traditional cigarette price with the traditional cigarette tax (*leave one out analysis*): Nielsen state-level sales data 2011-2017

Outcome:	**E-cigarettes**	**Traditional cigarettes**
Mean: e-cigarette tax adopting localities, in the year prior to the tax	1,236	56,468
Mean: traditional cigarette tax adopting localities, in the year prior to the first traditional cigarette tax increase	1,150	69,111
Exclude California		
E-cigarette price ($)	-627**	16,141***
	[-1,228,-27]	[4,902,27,380]
Traditional cigarette price ($)	115	-8,891***
	[-157,387]	[-14,423,-3,360]
Observations	1400	1400
Exclude Cook Co, IL		
E-cigarette price ($)	-246**	8,825***
	[-468,-24]	[2,485,15,165]
Traditional cigarette price ($)	193**	-8,569***
	[30,355]	[-13,318,-3,820]
Exclude Washington DC		
Observations	1400	1400
E-cigarette price ($)	-335**	9,663**
	[-666,-4]	[2,155,17,172]
Traditional cigarette price ($)	259**	-8,698***
	[40,478]	[-13,565,-3,832]
Observations	1400	1400
Exclude Kansas		
E-cigarette price ($)	-369**	9,468**
	[-721,-18]	[2,199,16,737]
Traditional cigarette price ($)	287**	-8,273***
	[56,518]	[-12,805,-3,740]
Observations	1400	1400
Exclude Louisiana		
E-cigarette price ($)	-410**	11,060**
	[-791,-30]	[2,490,19,629]
Traditional cigarette price ($)	316**	-9,821***
	[74,559]	[-14,958,-4,684]
Observations	1400	1400
Exclude Minnesota		
E-cigarette price ($)	-246	9,952**
	[-561,69]	[1,395,18,509]
Traditional cigarette price ($)	299***	-9,595***
	[79,520]	[-14,947,-4,243]
Observations	1400	1400
Exclude Montgomery Co, MD		
E-cigarette price ($)	-371**	-371**
	[-723,-19]	[-723,-19]
Traditional cigarette price ($)	284**	284**
	[52,516]	[52,516]
Observations	1400	1400
Exclude North Carolina		
E-cigarette price ($)	-363**	-363**
	[-706,-21]	[-706,-21]
Traditional cigarette price ($)	276**	276**

	[52,500]	[52,500]
Observations	1400	1400
Exclude Pennsylvania		
E-cigarette price ($)	-346*	-346*
	[-747,56]	[-747,56]
Traditional cigarette price ($)	272**	272**
	[53,491]	[53,491]
Observations	1400	1400
Exclude West Virginia		
E-cigarette price ($)	-358**	-358**
	[-708,-9]	[-708,-9]
Traditional cigarette price ($)	277**	277**
	[50,505]	[50,505]
Observations	1400	1400

Notes: 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. 95% confidence intervals that account for within-locality clustering are reported in square brackets. ┼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.

Appendix Table 6. Effect of e-cigarette taxes on flavored tobacco product sales per 100,000 state adult residents using a two-way fixed effects model: Nielsen retail sales locality-level data 2011-2017

Outcome:	**Non-flavored e-cigarettes**	**Menthol e-cigarettes**	**Flavored e-cigarettes**	**Non-flavored traditional cigarettes**	**Menthol traditional cigarettes**
E-cigarette tax ($)	-151*	-120**	-178**	9,190**	3,618**
	[-307,4]	[-230,-9]	[-331,-24]	[1,759,16,621]	[278,6,957]
Traditional cigarette tax ($)	80*	42	144***	-5,871**	-3,043***
	[-8,167]	[-29,112]	[59,229]	[-11,092,-649]	[-4,979,-1,107]
Observations	1428	1428	1428	1428	1428
Mean: e-cigarette tax adopting localities, in the year prior to the tax	519	363	351	41,965	14,502
Mean: traditional cigarette tax adopting localities, in the year prior to the first traditional cigarette tax increase	529	346	273	51,246	17,864

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. 95% confidence intervals that account for within-locality clustering are reported in square brackets. ***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.

Appendix Table 7. Effect of e-cigarette taxes on cigars, chewing tobacco, and loose tobacco sales per 100,000 state adult residents using a two-way fixed effects model: Nielsen retail sales locality-level data 2011-2017

Outcome:	**Cigars**	**Chewing tobacco**	**Loose tobacco**
E-cigarette	-785	134	-198
standardized tax ($)	[-2,239,670]	[-1,821,2,089]	[-554,158]
Traditional cigarette	612	-127	99
tax per pack ($)	[-424,1,648]	[-1,211,956]	[-129,327]
Observations	1428	1428	1428
Mean: e-cigarette tax adopting localities, in the year prior to the tax	4,382	6,279	557
Mean: traditional cigarette tax adopting localities, in the year prior to the first traditional cigarette tax increase	3,994	2,741	555

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. 95% confidence intervals that account for within-locality clustering are reported in square brackets. ***,**, and * = statistically different from zero at the 1%, 5%, and 10% level.