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ABSTRACT

Using NielsenIQ Retail Scanner data, we estimate demand equations for e-cigarettes by nicotine concentration. Overall, the models show that the price elasticities of demand range from -2.117 to -1.494. In a rapidly evolving e-cigarette market, demand for e-cigarettes varies considerably by nicotine strength. High-nicotine products, which have many close substitutes, are found to be more responsive to changes in price. Demand for low-nicotine products, with few close substitutes, are found to be less responsive to changes in price. Our findings also suggest that e-cigarettes with the lowest and highest nicotine concentrations may be economic complements, suggesting concurrent use. Unlike available evidence on cross-tax elasticities of demand, we find no evidence of an economic relationship between traditional cigarettes and e-cigarettes when broken down by nicotine strength concentration.

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1. Introduction

The market landscape of electronic nicotine delivery systems, also known as e-cigarettes, has experienced drastic changes since their introduction to the United States (U.S.) in the mid-2000s. [1] These products quickly gained popularity from 2016 to 2019, with total e-cigarette unit sales increasing nearly 300% during that time. [2] Youth e-cigarette use skyrocketed in tandem with rising sales: between 2011 to 2019, past 30-day e-cigarette use dramatically rose among high school students (from 1.5% to 27.5%) and middle school students (from 0.6% to 10.5%). [3] The latest data from the 2022 National Youth Tobacco Survey shows that more than 2.5 million American high school and middle school students have used e-cigarettes in the past 30 days. [4] Appealing flavors, high nicotine content, and advertising are some of the prominent factors that are attributed to youth e-cigarette use. [1] While adult use of e-cigarette products has remained relatively low, rates have steadily increased from 3.6% in 2020 to 5.8% in 2022. [5,6] However, adult prevalence rates vary by age, with current rates of 12.3% for 18–34-year-olds, 6.2% for 35-49-year-olds, 2.5% for 50-64-year-olds, and 1% for adults 65 and over, who report use of an electronic cigarettes in 2022. [7] These trends have raised substantial public health concerns, given nicotine's addictive nature [8] and its known role in harming brain development, particularly among youth users [1]. There is also concern based on evidence showing youth use of e-cigarettes increases the risk of subsequent initiation of combustible tobacco [9] and concern about their health effects. [10,11]

Since their introduction e-cigarettes have evolved in device types, flavors, and nicotine formulation, which in turn have affected consumers' demand and desire to purchase these products. First-generation devices resembled the look of regular cigarettes, known as cig-a-likes. These devices are now part of a diverse group of products and consumer options that include refillable products like SMOK tanks, pre-filled USB-like pod-base devices including JUUL and disposable devices like Puff Bar. [12–14] The market has also seen a rapid proliferation of e-cigarette flavors, with an estimated 15,586 distinct flavors available on the online market between 2016-2017, [15] and more recently with non-menthol cooling flavored disposable e-cigarette experiencing the highest sales growth amongst all e-cigarette products. [16] The type of nicotine used in e-liquids has also evolved from tobacco-derived free base nicotine, predominantly used in earlier e-cigarette products, to nicotine salts introduced by JUUL Labs, and more recently synthetic nicotine variations. [17,18] Nicotine salts made e-cigarettes more palatable by increasing appeal, sweetness, and smoothness, and lowering bitter and harsh flavor profiles. [19,20] Given these characteristics [21], the concentration of nicotine in e-cigarettes has also become stronger over time. Products with nicotine strengths above 4% grew from 12.3% of sales dollars in 2013 to 52.4% in 2017. [22] The average nicotine concentrations in e-cigarette products sold in the U.S. doubled from 2.1% in 2013 to 4.3% in 2018. [22] By March 2022, products with nicotine strength ≥5% accounted for almost 81% of total unit sales. [23]

Given the change in nicotine formulation, its addictive nature, and the rise in its concentration, we should expect demand estimates to vary. Limited prior research suggests that controlling for a certain product characteristic, such as nicotine strength, may change the demand for a product. For example, higher cigarette prices have been found to be positively correlated with sales of cigarettes with higher tar and nicotine content, [24] particularly among menthol cigarette smokers. [25] In addition, research has found associations among several aspects of nicotine content and e-cigarette use preferences. For example, amongst 18-24-year-old e-cigarette users, nicotine strength was described as one of the product's most important attributes. [26] Lastly, one study found that substitutability of alternative products for cigarettes increased as a function of e-liquid nicotine strength, with the products with the highest nicotine strength displaying the greatest substitutability. [27]

To our knowledge, no existing quasi-experimental work has attempted to estimate demand equations by nicotine concentration, especially during a period with marked increases in competition, product changes, and decreases in prices. Our research fills an important gap in the literature by evaluating demand for e-cigarette products at different nicotine strength levels. We also take advantage of our research design to further evaluate two important aspects of e-cigarette demand. First, given the empirically mixed findings on whether e-cigarettes are substitute or complementary goods to traditional cigarettes, we re-evaluate this economic relationship while controlling for nicotine concentration. Second, we evaluate whether e-cigarettes of different nicotine concentrations are used as substitutes or as complementary goods to one another. No research to date has tried to answer whether users of e-cigarettes consider e-cigarettes of different nicotine strength as a product that can be substituted in lieu of one another or if users prefer to consume e-cigarettes of differing nicotine strength together. Lastly, our research question also allows us to test economic theory. With the e-cigarette market currently valued at close to $7.5 billion, [28] economic theory suggests that as more products enter the market and competition increases, the prices of e-cigarette should decrease. [29] Similarly, as more e-cigarettes are introduced into the market, allowing for more substitution among brands, the e-cigarette own-price elasticity of demand should increase in absolute value. [30]

Our contributions to the literature are five-fold: First, we provide further evidence of a downward sloping demand curve for e-cigarettes. Second, we are the first to provide evidence of a downward sloping demand curve for e-cigarettes broken down by nicotine strength. Third, and unlike available evidence on cross-tax and price elasticities of demand, we find no evidence of an economic relationship between traditional cigarettes and e-cigarettes when broken down by nicotine strength; however, we do find an economic relationship between e-cigarettes with the highest and lowest nicotine strength concentrations. Fourth, we provide evidence to support the economic theory that as more products enter the market, the price of products will decrease. Lastly, we provide evidence to support the economic theory that as the number of substitute goods increases, the absolute value of the price elasticity of demand will also increase.

We have three primary findings. First, we find that the price elasticity of demand of e-cigarettes is between -2.1 and -1.5, in line with previous literature. We also find that the elasticity of demand increases in absolute value as nicotine concentration increases, increasing from 0.6 for e-cigarettes with less than or equal to 3% nicotine concentration, to 0.8 for those between 3%-5% nicotine concentration, to 1.3 for products with greater than or equal to 5% nicotine concentration. Second, we find that e-cigarettes with the highest nicotine concentrations – those available in the greatest numbers – are the most price elastic. Third, we find evidence of economic complementarity between e-cigarette products of the lowest-nicotine concentration and e-cigarette products of the highest-nicotine concentration, suggesting dual use.

Our paper is structured as follows. We first describe our data sources and measures (Section 2) and describe our empirical approach in detail (Section 3). We follow by presenting results for various demand models for nicotine strength with robustness checks (Section 4), followed by concluding remarks (Section 5).

2. Data Source and Measures

Outcome and main explanatory variables

The main data source for our analysis was the Stateline files from NielsenIQ Retail Scanner data for e-cigarettes. The data, licensed from NielsenIQ (Chicago, IL), contains universal product code (UPC) level data, sales dollars, and sales units from participating independent, chain and gas station convenience stores; food, drug, and mass merchandisers, discount, and dollar stores; and military commissaries. The data is provided in 4-week period aggregates, which we further aggregated to quarterly data from the first quarter of 2015 through the last quarter of 2021. The 23 states included in our sample are: Alabama, Arizona, California, Colorado, Florida, Georgia, Illinois, Indiana, Kentucky, Louisiana, Massachusetts, Michigan, Missouri, New Jersey, New York, North Carolina, Ohio, Oregon, Pennsylvania, Tennessee, Texas, Virginia, and Washington. As of 2021, these states accounted for 78 percent of the United States population and approximately 77 percent of all e-cigarette sales tracked by NielsenIQ. By the end of 2021 the 23 stateline files are further estimated to accounted for $3.9 billion in e-cigarette sales, which is approximately 53% of the market according to an industry report. [31]

We constructed four per capita dependent variables: overall milliliters of e-liquid sold, milliliters of e-liquid sold for products with less than 3% nicotine, between 3 and 5% nicotine, and greater than or equal to 5% nicotine. We calculated per capita milliliters of e-liquid sold by summing all milliliters of e-liquid sold in each state for each quarter, by nicotine strength categories, and dividing by state population figures from U.S. Census Bureau. [32]

Our main explanatory variable of interest was the sales weighted average price of one milliliter of e-liquid. We calculated this variable by summing total sales dollars, in each state for each quarter, and then dividing by total milliliters sold. Similar to our per capita dependent variables, we constructed the overall sales weighted average price for all products, and then for each of three nicotine strength groups. As constructed, this price variable is inclusive of all excise and wholesale taxes levied on e-cigarettes but does not include sales taxes that may be levied at the state level. We focused on per capita milliliters of e-liquid and not per unit prices of e-cigarettes as milliliter prices (henceforth referred to as price) provide a unifying measure that is easier to compare.

To construct both our dependent and explanatory variables we excluded products from the NielsenIQ dataset with no e-liquid such as hardware, batteries, and starter kits with no e-liquid, and non-nicotine containing products such as those sold with CBD, and wellness vapes (7.51 % of the data). We identified milliliters of e-liquid and nicotine strength data by using packaging characteristics provided to us by NielsenIQ and supplemented missing information by performing extensive online searches. We excluded 2% of barcodes that were missing milliliters, which account for less than 0.1% of total sales dollars. Nicotine strength information was available for all observations in our final dataset. Our final dataset consists of 1,446 unique barcodes and our final analytical sample included 644 state quarter periods.

Independent Variables

We include several time-varying tobacco control and state characteristic independent variables believed to affect the demand for e-cigarettes by various nicotine strengths. With regards to tobacco control independent variables, first, we included inflation-adjusted cigarette taxes at the state, year, and quarter level, which include the federal cigarette tax ($1.01 per pack), and state cigarette taxes (constructed from the Centers for Disease Control and Prevention State Tobacco Activities Tracking and Evaluation System). If a state implemented a cigarette excise tax at any time during a quarter, the data is weighted to reflect the days in the quarter the state excise tax was in place. Second, we include population-weighted comprehensive e-cigarette vape free air-laws for private workplaces using data from the American Nonsmoker Rights Foundation

(ANRF) [33]. This variable captures the percentage of the population in each state covered by a private workplace e-cigarette vape free air-law. Third, we included a measure that captures the percent of time in each quarter a flavored tobacco sales restrictions was in effect for the states of California, Massachusetts, New Jersey, and New York. [34] We do not however capture the 388 local flavored sales restrictions that have been implemented up until March 31, 2023 . [35] Fourth, we include a measure that captures inflation-adjusted per capita tobacco control spending in each state. This variable is based on the American Lung Association's annual State of Tobacco Control report. [36,37] Lastly, we included categorical indicator for state level e-cigarette minimum legal sales ages, which were either 18, 19, 20 or 21 and used no law as the excluded variable [38]. With regards to our state level independent variables, we control for the unemployment rate [39], median household income [40], beer excise taxes [41] and COVID-19 cases per 100,000 residents. [42] All nominal dollars are inflation adjusted to fourth quarter 2021 dollars using CPI from Bureau of Labor Statistics [39].

3. Empirical Approach

3.1. Overall Model

We start our analysis by estimating the demand for e-cigarettes irrespective of nicotine strength using a three-way fixed effects model, where we regress overall prices on overall per capita e-liquid milliliters sold. We estimate the following baseline regression model:

$$Y_{syq} = \beta_0 + \beta_1 ECigPrice_{syq} + \beta_2 X_{syq} + \beta_3 W_{syq} + \delta_s + \gamma_y + \lambda_q + \varepsilon_{syq} \quad (1)$$

where Y_{syq} is per capita e-liquid milliliters sold in each state of the 23 states in our data set *s*, during year *y* and quarter *q*. We include state fixed effects to control for time invariant unobserved factors at the state level, year fixed effects to control for unobserved changes in the distribution of per capita unit sales over time, and quarter fixed effects to control for unobserved per capita unit sale seasonality. Our identifying assumption in all our models is that, after controlling for state, year, and quarter fixed effects, there are no other unobserved factors that are correlated with both real prices and per capita milliliter sales.

After our first model, we estimate an additional nine models, where we iteratively enter each independent tobacco control variable from vector, X_{syq}, and each independent state characteristic variable from vector, W_{syq}. Our tobacco control vector includes real cigarette taxes, the percentage of the population in each state covered by a private workplace e-cigarette vape free air-law, the ratio of days in each quarter a flavored tobacco sales restrictions was in place, real per capita tobacco control spending, and categorical indicators of e-cigarette minimum legal sales ages. Our state characteristics vector includes the unemployment rate, real median household income, real excise beer taxes, and COVID-19 cases per 100,000 residents. We include both cigarette and beer excise taxes in our final model to control for possible economic substitution or complementarity among products. If our identifying assumptions hold, we do not expect the addition of these covariates to significantly alter the estimates of $\beta 1$. For all models we use robust standard errors and cluster at the state level.

3.2. Nicotine Strength Models

To expand our knowledge on the intricacies of the e-cigarette market and how it has changed over time, we re-estimated the demand for e-cigarette products by estimating three separate demand equations based on nicotine content. To estimate a causal relationship, we modeled three-way fixed-effects demand equation models for: e-cigarettes with less than 3% nicotine, between 3 and 5% nicotine, and greater than or equal to 5% nicotine. As such, we modify equation 1 and estimate the following baseline regression model for each nicotine strength outcome:

$$Y_{\%nsyq} = \beta_0 + \beta_1 ECigPrice_{\%nsyq} + \beta_2 X_{syq} + \beta_3 W_{syq} + \delta_s + \gamma_y + \lambda_q + \varepsilon_{syq} \qquad (2)$$

where $Y_{\%nsyq}$ is per capita e-liquid milliliters sold for each of our three nicotine strength categories, *%n,* in each state *s,* during year *y* and quarter *q.* Our main outcome and explanatory variable was subsetted for products with less than 3% nicotine, between 3 and 5% nicotine, and greater or equal than 5% nicotine. To directly compare our results to those of our overall model (Equation 1) we run three regression models for each nicotine strength category. Our first model includes state, year, and quarter fixed effects, our second model adds our tobacco control vector, X_{syq}, and our third model adds our state characteristic vector, W_{syq}.

3.3. Economic Relationship Nicotine Strength Models

We modify equation 2 to estimate the economic relationship between products of different nicotine strengths by including in each equation the price of all three nicotine strength groups.

$$\sum_{i=1}^{3} Y_{\%nisyq} = \beta_0 + \beta_1 ECigPrice_{\%n1syq} + \beta_2 ECigPrice_{\%n2syq} + \beta_3 ECigPrice_{\%n3syq} + \beta_4 X_{syq} + \beta_5 W_{syq} + \delta_s + \gamma_y + \lambda_q + \varepsilon_{syq} \qquad (3)$$

While equation 3 allows us to estimate the economic relationship between products of different nicotine strengths, we expected there to be collinearity between all the price variables. To properly measure how much these variables are correlated with one another we calculate variance inflation factors (VIF).

3.4. Price Endogeneity, instrumenting prices with taxes

Lastly, there is the possibility that the prices we employ in our regressions are endogenous. We therefore re-estimate equation 1 and 2 using an instrumental variables (IV) model where we instrument for prices using the standardized tax rates provided by Cotti and colleagues. [43] Unfortunately, this publicly available dataset only goes through the fourth quarter of 2020, so we lose a full year of data in this analysis.

4. Results

4.1. Descriptive Relationships

Table 1 presents summary statistics for our outcomes, main explanatory variables, and state level tobacco control and characteristic used as covariates. Total per capita e-liquid sales averaged 0.52 mL per state year quarter. When broken down by our three nicotine strength categories, less than or equal to 3% nicotine strength, between 3% and 5% nicotine strength, and greater than or equal to 5% nicotine strength, total per capita e-liquid sales averaged 0.14, 0.07, and 0.34 mLs per state year quarter respectively[1]. The sales weighted average price of one mL of e-liquid, adjusted to 2021 Q4 dollars, was $5.11. When broken down by nicotine strength category, the real sales weighted average price per one mL were $3.69, $6.48, and $6.35, for e-cigarettes with less than or equal to 3% nicotine strength, between 3% and 5% nicotine strength, and greater than or equal to 5% nicotine strength respectively. To further contextualize our data, Figures 1-3 provide averages over time for per capita e-liquid sales, the real sales weighted average price per mL of e-liquid, and the number of new bar codes for each nicotine concentration category.

[1] The three nicotine concentration categories do not add up to 0.52 mLs per state year quarter, because earlier quarters for some states do not have per capita sales with products containing greater than or equal to 5% nicotine strength.

Table 1. Summary Statistics

	Observations	Mean (Std. Dev.)
Outcome Variable		
Total Per Capita E-cigarette mL Sold	644	0.52 (0.46)
Total Per Capita E-cigarette mL Sold ≤ 3% Nicotine Strength	644	0.14 (0.07)
Total Per Capita E-cigarette mL Sold > 3% & < 5% Nicotine Strength	644	0.07 (0.03)
Total Per Capita E-cigarette mL Sold ≥ 5% Nicotine Strength	603	0.34 (0.43)
Sales Weighted Average Price (p/one mL, 2021 Q4 Dollars)		
E-Cigarette Price	644	$5.11 (1.03)
E-Cigarette Price ≤ 3% Nicotine Strength	644	$3.69 (0.73)
E-Cigarette Price > 3% & < 5% Nicotine Strength	644	$6.48 (0.95)
E-Cigarette Price ≥ 5% Nicotine Strength	644	$6.35 (2.38)
State-Level Tobacco Control Policies (Vector X)		
Real Cigarette Tax (2021 Q4 Dollars)	644	$2.89 (1.22)
Real E-cigarette Tax (2021 Q4 Dollars)	644	$0.13 (0.42)
Private Workplace E-Cigarette Free Air Laws (Population %)	644	30.45% (37.29)
Percentage of days with a flavor ban in effect for CA, MA, NJ, and NY State	644	3.36% (17.76)
Per Capita Total Funding for State Tobacco Control Programs (2021 Q4 Dollars)	644	$1.62 (1.47)
Minimum Legal Sales Age (Ref: No law)	644	1.64 (1.30)
State-Level Characteristics (Vector W)		
State-Level Unemployment Rate	644	5.09% (2.05)
Median Household Income (2021 Q4 Dollars)	644	$76,039 (11,248)
Real State Beer Excise Tax (per gallon – 2021 Q4 Dollars)	644	$0.34 (0.36)
State reported COVID-19 Cases per 100,000 people	644	0.66 (1.74)

Figure 1 depicts average per capita mL e-liquid sales, broken out by the three nicotine strength categories. Average per capita sales for all three groups remained steady until the second quarter of 2018. Coinciding with the rise in popularity of Juul, the average per capita mL e-liquid sales with the highest nicotine strength increased from 0.0002 to 1.36 mLs/person, a 680,000% increase in per capita mL e-liquid sales.

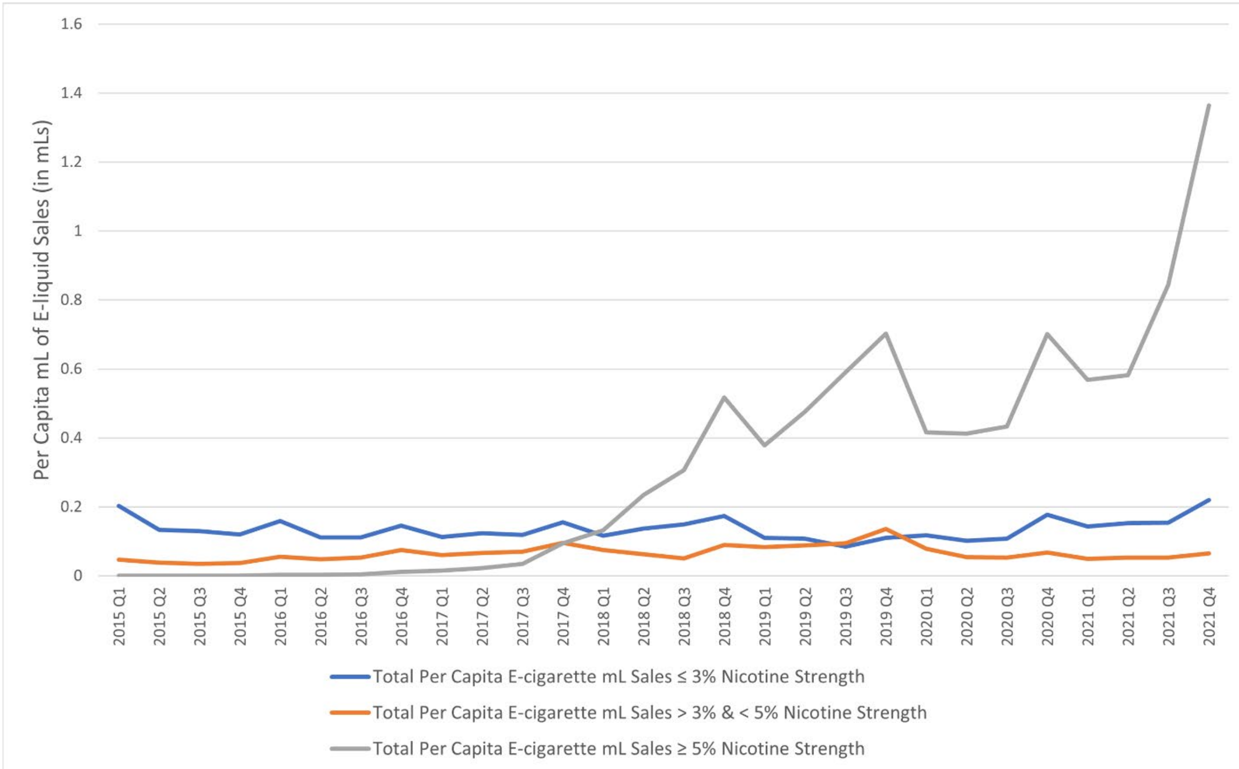

Figure 1 – Average per capita e-liquid mL sales over time by nicotine strength group, NielsenIQ Retail Sales Data 2015 Q1 – 2021 Q4.

Figure 2 depicts the real sales weighted average price per one mL of e-liquid, again broken out by the three nicotine strength categories. While sales weighted average prices with the lowest and mid-level nicotine content remained fairly steady throughout our study period, the price per one mL of e-liquid with the highest concentration of nicotine increased four-fold from $1.91 to $8.52 in the first three quarters of 2015. This increase coincides with the introduction of Juul and their nicotine salt formulation that enabled higher concentrations of nicotine. [44] Over time however, the price of one mL of e-liquid in this nicotine strength category continued to decrease post its peak in the third quarter of 2015, with a total 52.1% decrease from the third quarter of 2015 throughout the end of our study period in the fourth quarter of 2021. This finding is consistent with Diaz et al. (2021). [45] By the end of our study period, e-cigarettes with the mid-level nicotine content became the most expensive at $5.98, followed by the highest level of nicotine content at $4.08, and the lowest nicotine content at $3.30.

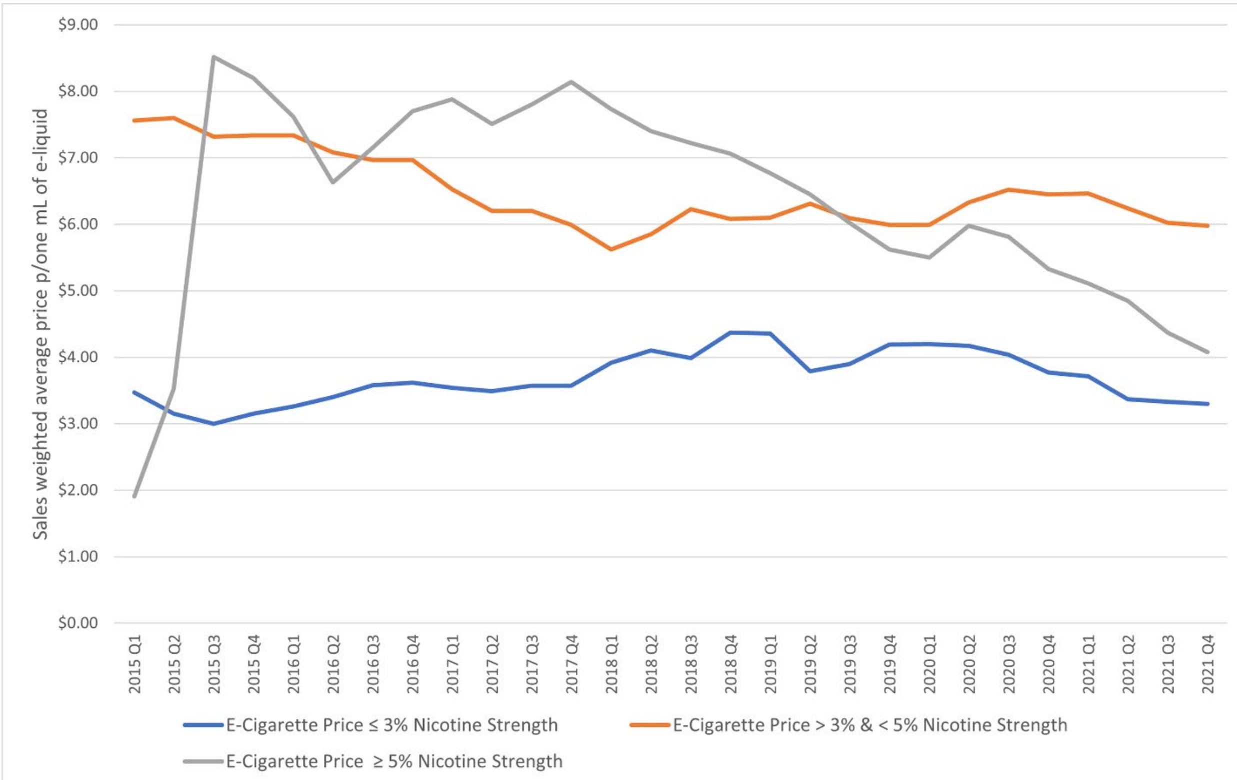

Figure 2 – Sales weighted average price p/one mL (2021 Q4 Dollars), NielsenIQ Retail Sales Data 2015 Q1 – 2021 Q4.

Figure 3 shows the number of unique UPC barcodes in the 23 Nielsen states between the first quarter of 2015 and the last quarter of 2021, broken down by our three nicotine strength categories. Products with the lowest nicotine content, e-cigarettes with less than or equal to 3% nicotine strength, start out with the largest number of UPCs, 770, and steadily decrease to 157 by December 2021. Both higher nicotine e-cigarette groups, those with nicotine concentration between 3% and 5% and those with greater than or equal to 5% nicotine strength, start with less than 60 unique UPC's. However, between the beginning of the third quarter of 2021 and the end of the fourth quarter of 2021, products with the largest nicotine concentration substantially increase from 167 to 1242 unique UPC's (743% growth), while the number of UPC's in the mid-level nicotine content remain steady.

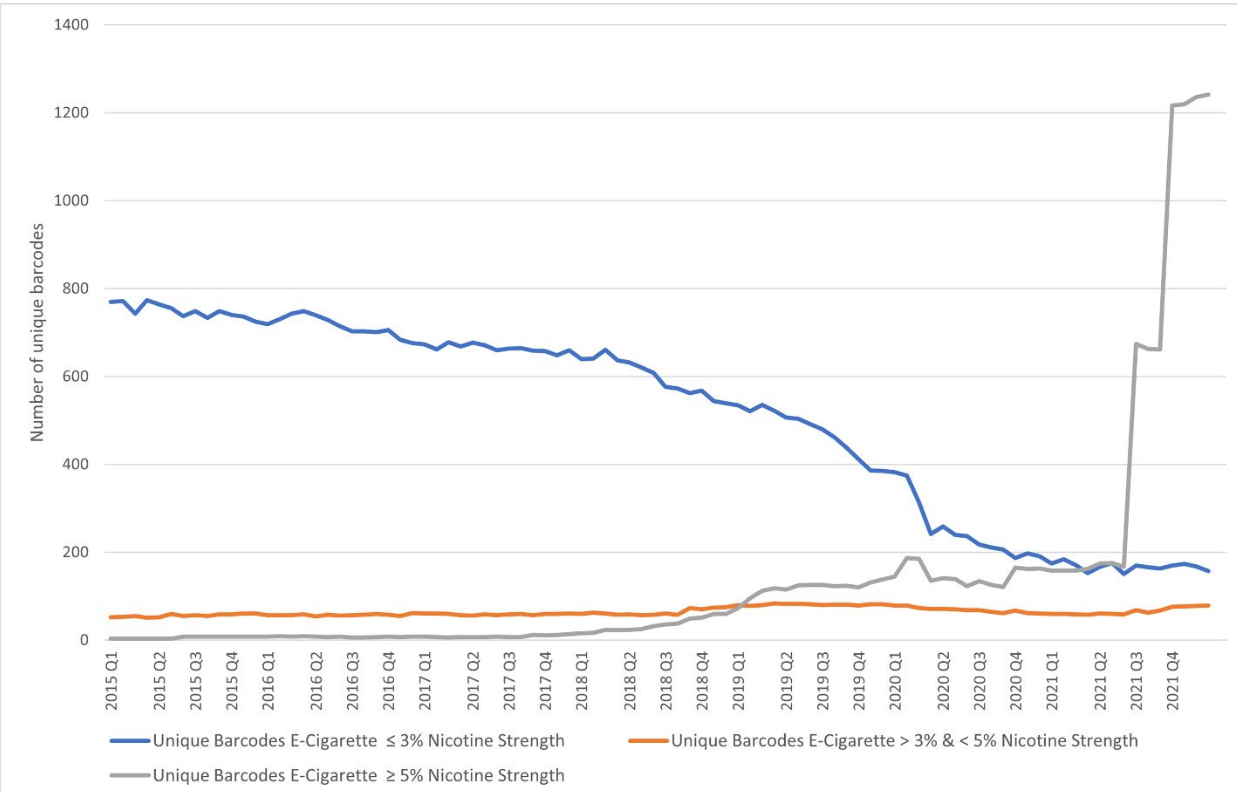

Figure 3 – Number of unique barcodes over time by nicotine strength group, NielsenIQ Retail Sales Data 2015 Q1 – 2021 Q4.

4.2.Overall model results

We find e-cigarette prices to have a negative and statistically significant effect on per-capita millimeters sold in all ten models that do not take into account nicotine strength (Equation 1, Table 2). The price elasticities of demand range from -2.117 to -1.494. In model 10, which includes all the explanatory variables simultaneously, our estimated price elasticity of demand is -1.578.

Table 2. Three-way Fixed Effects Analysis, Estimates of the Effect of E-cigarette Prices on Total Per-Capita E-Cigarette mL Sold. Nielsen IQ Retail Sales Data 2015 Q1 – 2021 Q4

Model Number:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Outcome:	Total Per Capita E-cigarette mL Sold									
Sales Weighted Average E-Cigarette Price (p/one mL – 2021 Q4 Dollars)	-0.193***	-0.214***	-0.212***	-0.165***	-0.161***	-0.161***	-0.157***	-0.151***	-0.153***	-0.160***
	(0.0391)	(0.0404)	(0.0396)	(0.0449)	(0.0462)	(0.0460)	(0.0450)	(0.0430)	(0.0460)	(0.0476)
Total Cigarette Taxes (p/one pack – 2021 Q4 Dollars)		0.095	0.101	0.00935	0.0408	0.0456	0.0490	0.0480	0.0581	0.0573
		(0.0615)	(0.0593)	(0.0481)	(0.0484)	(0.0469)	(0.0469)	(0.0466)	(0.0502)	(0.0491)
Private Workplace E-Cigarette Free Air Laws (Population %)			-0.123	-0.0505	-0.0569	-0.0497	-0.0440	-0.0458	-0.0341	-0.0236
			(0.1000)	(0.0799)	(0.0773)	(0.0811)	(0.0780)	(0.0774)	(0.0749)	(0.0626)
E-cigarette Temporary Flavor Ban for CA, MA, NJ, and NY States (percent of each quarter)				-0.524***	-0.508***	-0.501***	-0.468***	-0.466***	-0.439***	-0.432***
				(0.0996)	(0.0940)	(0.0992)	(0.1034)	(0.0901)	(0.1012)	(0.1106)
Per Capita Total Funding for State Tobacco Control Programs (2021 Q4 Dollars)					-0.043***	-0.045***	-0.044***	-0.044***	-0.043***	-0.038**
					(0.0136)	(0.0125)	(0.0126)	(0.0130)	(0.0143)	(0.0141)
E-Cigarette Minimum Legal Sales Age Laws						-0.011	-0.012	-0.005	-0.004	-0.005
						(0.0234)	(0.0229)	(0.0211)	(0.0223)	(0.0211)
State-Level Unemployment Rate							-0.015	-0.015	-0.014*	-0.012*
							(0.0101)	(0.0100)	(0.0078)	(0.0065)
Median Household Income (2021 Q4 Dollars)								-0.000	-0.000	-0.000
								(0.0000)	(0.0000)	(0.0000)
State Beer Excise Taxes (per gallon – 2021 Q4 Dollars)									-1.826	-1.852
									(2.1959)	(2.1820)
State Reported COVID-19 Cases per 100,000 people										-0.018
										(0.0124)
Fixed Effects:										
State	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Quarter	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Constant	0.901***	0.716***	0.703***	0.756***	0.719***	0.713***	0.764***	1.495***	2.006**	2.054**
	(0.1391)	(0.1664)	(0.1532)	(0.1402)	(0.1434)	(0.1375)	(0.1571)	(0.3885)	(0.8642)	(0.8742)
Observations	644	644	644	644	644	644	644	644	644	644
R-squared	0.664	0.668	0.670	0.696	0.699	0.700	0.702	0.706	0.711	0.714
Number of States	23	23	23	23	23	23	23	23	23	23
Own-Price Elasticity	-1.912***	-2.117***	-2.092***	-1.631***	-1.597***	-1.590***	-1.554***	-1.494***	-1.513***	-1.578***
	(0.3871)	(0.3995)	(0.3919)	(0.4437)	(0.4567)	(0.4545)	(0.4451)	(0.4256)	(0.4548)	(0.4712)
Cigarette Cross-Tax Elasticity		0.531	0.564	0.052	0.229	0.255	0.274	0.269	0.326	0.321
		(0.3447)	(0.3319)	(0.2693)	(0.2708)	(0.2629)	(0.2629)	(0.2611)	(0.2809)	(0.2753)

*** p <0.01, ** p<0.05, * p<0.1

Robust standard errors in parenthesis, standard errors are clustered at the state level. Columns 2-6 iterative include components of our tobacco control vector, *Xsyq*. Columns 7-10 interactively include components of our state characteristic vector, *Wsyq*.

Price and tax elasticities are calculated at the means using the margins command from STATA 17

We also find a significant inverse relationship between state expenditures on tobacco control programs and e-cigarette demand. This finding is consistent with Tauras et al. (2021) who also found that funding state tobacco control programs leads to reductions in high school student vaping in the United States. [37] Moreover, we found a strong negative relationship between e-cigarette flavor bans in CA, MA, NJ and NY and e-cigarette sales, consistent with Ali et al. (2022) and Satchel et al. (2022). [46,47]

4.3. Models by nicotine strength

When we subset e-cigarettes according to nicotine strength, we find again that price has a negative and statistically significant impact on e-cigarette demand, but the estimated price elasticities differ by nicotine strength (Equation 2, Table 3). Specifically, we found that e-cigarettes with the lowest nicotine content (less than 3% nicotine) are the least price elastic with an estimated price elasticity of demand between -0.536 and -0.575; the e-cigarettes with the mid-level nicotine content (between 3 and 5% nicotine) are more price elastic than the lowest nicotine content cigarette with an estimated price elasticity of demand between -0.748 and -0.858; the e-cigarettes with the highest nicotine content (5% or greater nicotine) are the most price elastic with an estimated price elasticity of demand between -1.316 and -1.837**.** The finding of a positive relationship between nicotine content and the absolute price elasticity of demand is not surprising. Economic theory suggests that one of the most important determinants of the price elasticity of demand is the number of close substitutes. [30] Since 2017, there has been tremendous growth in the number of close substitutes for 5% or greater nicotine content e-cigarettes. The number of unique UPC’s in the 5% or greater nicotine content e-cigarette category increased from 3 unique UPC’s in 2015 to more than 1,200 by the end of 2021. At the same time the price of 5% or greater nicotine content e-cigarettes has declined substantially from a sales weighted average price of $8.52 per mL of e-liquid in 2017 to $4.08 in 2021. In comparison, the number of substitutes within the lower nicotine content e-cigarette categories have been decreasing. In particular, the number of unique UPCs in the less than 3% and between 3 and 5% nicotine content e-cigarette categories have been falling since 2015 and 2019, respectively, and the prices of these products has been more stable over time than the high nicotine content e-cigarettes.

E-cigarette flavor bans in CA, MA, NJ and NY are found to be inversely related to e-cigarette sales in the low and high nicotine content products but are found to have no relationship with e-cigarettes products with mid-levels of nicotine. We also find an inverse relationship between state expenditures on tobacco control programs and e-cigarette demand, but this finding is only significant at the 5% level of a two-tailed test for the highest nicotine products category.

Table 3. Three-way Fixed Effects Analysis, Estimates of the Effect of E-cigarette Prices by Nicotine Strength on Total Per-Capita E-Cigarette mL Sold by Nicotine Strength. Nielsen IQ Retail Sales Data 2015 Q1 – 2021 Q4

Model Number:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Outcome:	Total Per Capita E-cigarette mL Sold ≤ 3% Nicotine Strength			Total Per Capita E-cigarette mL Sold > 3% & < 5% Nicotine Strength			Total Per Capita E-cigarette mL Sold ≥ 5% Nicotine Strength		
Sales Weighted Average E-Cigarette Price (p/one mL–2021 Q4 Dollars)									
E-Cigarette Price ≤ 3% Nicotine Strength	-0.020***	-0.021***	-0.021***						
	(0.0067)	(0.0070)	(0.0061)						
E-Cigarette Price > 3% & < 5% Nicotine Strength				-0.008**	-0.008*	-0.009*			
				(0.0033)	(0.0041)	(0.0043)			
E-Cigarette Price ≥ 5% Nicotine Strength							-0.091***	-0.069**	-0.065***
							(0.0225)	(0.0254)	(0.0219)
Total Cigarette Taxes (p/one pack – 2021 Q4 Dollars)		-0.003	-0.003		0.001	0.001		-0.000	0.008
		(0.0073)	(0.0083)		(0.0055)	(0.0056)		(0.0366)	(0.0356)
Private Workplace E-Cigarette Free Air Laws (Population %)		0.018	0.017		0.001	0.001		-0.022	-0.002
		(0.0138)	(0.0127)		(0.0048)	(0.0056)		(0.0658)	(0.0549)
E-cigarette Temporary Flavor Ban for CA, MA, NJ, and NY States (percent of each quarter)		-0.177***	-0.177***		0.008	0.008		-0.366***	-0.320***
		(0.0381)	(0.0348)		(0.0152)	(0.0147)		(0.0721)	(0.0824)
Per Capita Total Funding for State Tobacco Control Programs (2022 Q3 Dollars)		-0.002	-0.002		-0.001	-0.000		-0.040**	-0.036**
		(0.0028)	(0.0031)		(0.0015)	(0.0016)		(0.0156)	(0.0158)
E-Cigarette Minimum Legal Sales Age Laws		-0.002	-0.000		0.000	0.000		-0.007	-0.002
		(0.0034)	(0.0033)		(0.0016)	(0.0016)		(0.0229)	(0.0227)
State-Level Unemployment Rate			-0.000			-0.000			-0.010*
			(0.0009)			(0.0004)			(0.0050)
Median Household Income (2021 Q4 Dollars)			-0.000***			-0.000			-0.000
			(0.0000)			(0.0000)			(0.0000)
State Beer Excise Taxes (per gallon – 2021 Q4 Dollars)			-0.004			0.116			-1.503
			(0.0902)			(0.0732)			(2.7220)
State Reported Covid Cases per 100,000 people			-0.001			-0.001**			-0.014
			(0.0017)			(0.0006)			(0.0107)
Fixed Effects:									
State	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year	Y	Y	Y	Y	Y	Y	Y	Y	Y
Quarter	Y	Y	Y	Y	Y	Y	Y	Y	Y
Constant	0.213***	0.228***	0.466***	0.094***	0.096***	0.0110**	0.671***	0.519***	1.645
	(0.0232)	(0.0318)	(0.0793)	(0.0250)	(0.0189)	(0.0397)	(0.1924)	(0.1835)	(1.0204)
Observations	644	644	644	644	644	644	603	603	603
R-squared	0.250	0.512	0.538	0.598	0.600	0.612	0.660	0.681	0.690
Number of States	23	23	23	23	23	23	23	23	23
Own-Price Elasticity	-0.536***	-0.569***	-0.575***	-0.748**	-0.779*	-0.858**	-1.837***	-1.379***	-1.316***
	(0.1834)	(0.1910)	(0.1656)	(0.3275)	(0.4087)	(0.4235)	(0.5064)	(0.5112)	(0.4405)
Cigarette Cross-Tax Elasticity		-0.074	-0.055		0.024	0.028		-0.002	0.069
		(0.1572)	(0.1768)		(0.2414)	(0.2500)		(0.3147)	(0.3054)

*** p <0.01, ** p<0.05, * p<0.1 Robust standard errors in parenthesis, standard errors are clustered at the state level. Price and tax elasticities are calculated at the means using the margins command from STATA 17

4.4. Models by nicotine strength allowing for cross-price effects between categories of nicotine content

In Table 4 we present demand equation estimates that include prices for all nicotine strength categories (Equation 3). For each demand equation by nicotine strength, own price is found to have a significant negative impact on the demand for all three nicotine content e-cigarette categories. However, the cross-price effects differ between categories of e-cigarettes based on nicotine content. The price of the highest nicotine category is found to have a negative and significant impact on the lowest nicotine category e-cigarette sales indicating that these two products are economic complements for one another. Similarly, the price of the lowest nicotine category is found to have a negative and significant impact on the highest nicotine category e-cigarette sales indicating again that these two products are economic complements for one another. The relationship between the demand for mid-level nicotine content e-cigarettes and the prices of the other two nicotine category products is generally statistically insignificant. It should be noted that there is a possibility of collinearity between the prices of the different categories of nicotine products. A look at Figure 2 suggests that the prices of the two lowest nicotine product categories may be most worrisome from a multicollinearity perspective as they track a very similar pattern beginning in 2018. We calculate variance inflation factors (VIFs) in all the models that include multiple prices of e-cigarette products and find there is some degree of collinearity with the majority of VIF’s exceeding 10 in all the models.

Table 4. Three-way Fixed Effects Analysis, Estimates of the Effect of E-cigarette Prices by Nicotine Strength Group. Nielsen IQ Retail Sales Data 2015 Q1 – 2021 Q4

Model Number:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Outcome:	Total Per Capita E-cigarette mL Sold ≤ 3% Nicotine Strength			Total Per Capita E-cigarette mL Sold > 3% & < 5% Nicotine Strength			Total Per Capita E-cigarette mL Sold ≥ 5% Nicotine Strength		
Sales Weighted Average E-Cigarette Price (p/one mL–2021 Q4 Dollars)									
E-Cigarette Price ≤ 3% Nicotine Strength	-0.017*	-0.022***	-0.023***	0.003	0.004	0.004	-0.036	-0.049*	-0.057**
	(0.0082)	(0.0065)	(0.0057)	(0.0025)	(0.0037)	(0.0037)	(0.0227)	(0.0243)	(0.0264)
E-Cigarette Price > 3% & < 5% Nicotine Strength	-0.004	0.007	0.007	-0.008**	-0.008**	-0.009**	-0.005	0.012	0.032
	(0.0079)	(0.0045)	(0.0046)	(0.0030)	(0.0038)	(0.0041)	(0.0246)	(0.0261)	(0.0268)
E-Cigarette Price ≥ 5% Nicotine Strength	-0.004***	-0.003***	-0.003**	-0.001	-0.001	-0.001**	-0.088***	-0.070**	-0.070***
	(0.0012)	(0.0009)	(0.0010)	(0.0004)	(0.0004)	(0.0004)	(0.0249)	(0.0252)	(0.0242)
Total Cigarette Taxes (p/one pack – 2021 Q4 Dollars)		-0.006	-0.006		-0.001	-0.000		0.018	0.015
		(0.0087)	(0.0093)		(0.0065)	(0.0068)		(0.0500)	(0.0487)
Private Workplace E-Cigarette Free Air Laws (Population %)		0.018	0.017		0.003	0.004		-0.046	-0.030
		(0.0149)	(0.0131)		(0.0050)	(0.0059)		(0.0716)	(0.0673)
E-cigarette Temporary Flavor Ban for MA, MI, OR, and WA States (percent of each quarter)		-0.178***	-0.179***		0.009	0.009		-0.367***	-0.331***
		(0.0390)	(0.0364)		(0.0158)	(0.0158)		(0.0787)	(0.0903)
Per Capita Total Funding for State Tobacco Control Programs (2021 Q4 Dollars)		-0.003	-0.002		-0.001	-0.001		-0.038**	-0.034**
		(0.0030)	(0.0033)		(0.0017)	(0.0018)		(0.0147)	(0.0143)
E-Cigarette Minimum Legal Sales Age Laws		-0.003	-0.001		0.000	0.001		-0.008	-0.004
		(0.0034)	(0.0032)		(0.0017)	(0.0016)		(0.0231)	(0.0219)
State-Level Unemployment Rate			0.000			-0.000			-0.009
			(0.0010)			(0.0004)			(0.0059)
Median Household Income (2021 Q4 Dollars)			-0.000***			-0.000			-0.000
			(0.0000)			(0.0000)			(0.0000)
State Beer Excise Taxes (per gallon – 2021 Q4 Dollars)			0.036			0.150*			-1.714
			(0.1042)			(0.0841)			(2.8650)
State Reported COVID-19 Cases per 100,000 people			-0.001			-0.001**			-0.017
			(0.0017)			(0.0006)			(0.0110)
Fixed Effects:									
State	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year	Y	Y	Y	Y	Y	Y	Y	Y	Y
Quarter	Y	Y	Y	Y	Y	Y	Y	Y	Y
Constant	0.256***	0.207***	0.427***	0.091***	0.093***	0.095**	0.790***	0.544**	1.707
	(0.0553)	(0.0418)	(0.0858)	(0.0288)	(0.0215)	(0.0416)	(0.2390)	(0.2114)	(1.0283)
Observations	644	644	644	644	644	644	603	603	603
R-squared	0.275	0.524	0.550	0.601	0.605	0.620	0.662	0.683	0.693
Number of States	23	23	23	23	23	23	23	23	23
Model Mean VIF	10.24	9.63	13.97	10.24	9.63	13.97	19.03	16.08	18.79
Price Elasticity ≤ 3% Nicotine Strength	-0.453**	-0.604***	-0.620***	0.159	0.220	0.206	-0.400	-0.539**	-0.629**
	(0.2245)	(0.1778)	(0.1543)	(0.1437)	(0.2070)	(0.2112)	(0.2503)	(0.2680)	(0.2907)
Price Elasticity > 3% & < 5% Nicotine Strength	-0.215	0.313	0.336	-0.784***	-0.811**	-0.893**	-0.092	0.230	0.606
	(0.3775)	(0.2136)	(0.2195)	(0.2958)	(0.3729)	(0.4035)	(0.4669)	(0.4955)	(0.5092)
Price Elasticity ≥ 5% Nicotine Strength	-0.172***	-0.128***	-0.123***	-0.054	-0.060	-0.096**	-1.761***	-1.402***	-1.400***
	(0.0567)	(0.0431)	(0.0456)	(0.0415)	(0.0369)	(0.0426)	(0.5007)	(0.5069)	(0.4862)
Cigarette Cross-Tax Elasticity		-0.137	-0.133		-0.038	-0.019		0.157	0.131
		(0.1853)	(0.1990)		(0.2899)	(0.2994)		(0.4292)	(0.4184)

*** p <0.01, ** p<0.05, * p<0.1

Robust standard errors in parenthesis, standard errors are clustered at the state level. Price and tax elasticities are calculated at the means using the margins command from STATA 17

4.5. Instrumental variables models using prices as an instrument for taxes

In Table 5 we present 2-stage least squares demand equation estimates that account for possible endogeneity in the price variables we present in Table 3. An important caveat for this analysis is that the tax data was only available through the fourth quarter of 2020, reducing our sample size when compared to our other results. Using the state's e-cigarette tax as an instrument for e-cigarette prices we find negative estimates, but statistical precision varies. The lack of precision could stem from the fact that standard errors from 2-stage least squares regressions tend to be large. Notably, we find that e-cigarettes with the highest nicotine content are again the most price elastic with an estimated price elasticity of demand between -2.203 and -2.653. The finding that these price elasticities are larger in absolute value than those found in Table 3 is also not surprising, as elasticities calculated with instrumental variables tend to be larger.

To test for under-identification in our models, we use the Kleibergen-Paap rk LM statistic for all first stage instrumental variable models and find that we can reject the null that the model is under-identified. In addition, and since estimators can perform poorly when instruments are weak, we used the Kleibergen-Paap rk Wald F statistic for weak instruments and find that we can reject the null that there is a presence of a weak instrument in eight out of our 10 models. For models 2 and 3, which focus on products with the lowest nicotine content, we cannot reject the null of weak instruments.

When compared to all our results presented thus far, Model 4 is the only equation where we find statistical significance for an estimated cigarette cross-tax elasticity of -0.99 for e-cigarettes with the lowest nicotine content. This finding implies that an increase in cigarette taxes would lead to a decrease in total per capita e-cigarette sales for e-cigarettes with less than 3% nicotine concentration. The result of economic complementary between cigarettes and e-cigarettes has thus far been mixed, with most papers finding economic substitution between cigarettes and e-cigarettes. [48–55]

5. **Table 5. Instrumental Variables Analysis, Estimates of the Effect of E-cigarette Prices by Nicotine Strength Group. Nielsen IQ Retail Sales Data 2015 Q1 – 2020 Q4**

Model Number:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Outcome:	Total Per Capita E-cigarette mL Sold	Total Per Capita E-cigarette mL Sold ≤ 3% Nicotine Strength			Total Per Capita E-cigarette mL Sold > 3% & < 5% Nicotine Strength			Total Per Capita E-cigarette mL Sold ≥ 5% Nicotine Strength		
Sales Weighted Average E-Cigarette Price (p/one mL – 2021 Q4 Dollars)	-0.094									
	(0.0714)									
E-Cigarette Price ≤ 3% Nicotine Strength		-0.043	0.044	0.042*						
		(0.0327)	(0.0274)	(0.0254)						
E-Cigarette Price > 3% & < 5% Nicotine Strength					-0.007*	0.003	0.002			
					(0.0035)	(0.0080)	(0.0081)			
E-Cigarette Price ≥ 5% Nicotine Strength								-0.091***	-0.076**	-0.077**
								(0.0165)	(0.0307)	(0.0314)
Total Cigarette Taxes (p/one pack – 2021 Q4 Dollars)	0.027		-0.040*	-0.044*		-0.011	-0.010		0.046	0.047
	(0.0654)		(0.0244)	(0.0234)		(0.0086)	(0.0090)		(0.0412)	(0.0401)
Private Workplace E-Cigarette Free Air Laws (Population %)	-0.008		0.040*	0.038*		-0.003	-0.003		0.020	0.026
	(0.0516)		(0.0218)	(0.0198)		(0.0069)	(0.0071)		(0.0499)	(0.0488)
E-cigarette Temporary Flavor Ban for MA, MI, OR, and WA States (percent of each quarter)	-0.370***		-0.143***	-0.137***		-0.016	-0.012		-0.181**	-0.148*
	(0.1329)		(0.0302)	(0.0266)		(0.0150)	(0.0150)		(0.0848)	(0.0869)
Per Capita Total Funding for State Tobacco Control Programs (2021 Q4 Dollars)	-0.030***		-0.004	-0.004		-0.002	-0.001		-0.026**	-0.024**
	(0.0111)		(0.0049)	(0.0053)		(0.0024)	(0.0023)		(0.0114)	(0.0109)
E-Cigarette Minimum Legal Sales Age Laws	-0.018		-0.001	0.001		-0.002	-0.002		-0.011	-0.010
	(0.0129)		(0.0047)	(0.0047)		(0.0018)	(0.0017)		(0.0140)	(0.0118)
State-Level Unemployment Rate	-0.011**			-0.002			-0.001			-0.008**
	(0.0050)			(0.0012)			(0.0005)			(0.0040)
Median Household Income (2021 Q4 Dollars)	-0.000			-0.000***			-0.000			-0.000
	(0.0000)			(0.0000)			(0.0000)			(0.0000)
State Beer Excise Taxes (per gallon – 2021 Q4 Dollars)	-1.122			-0.007			-0.002			-0.407
	(1.2613)			(0.1602)			(0.0586)			(1.7270)
State Reported COVID-19 Cases per 100,000 people	0.000			0.009**			-0.003**			-0.001
	(0.0121)			(0.0045)			(0.0012)			(0.0081)
Fixed Effects:										
State	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Quarter	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Constant	1.151**	0.293***	0.127**	0.346***	0.088***	0.051	0.100***	0.710***	0.478***	0.686
	(0.5000)	(0.1094)	(0.0581)	(0.0940)	(0.0260)	(0.0377)	(0.0360)	(0.1396)	(0.1792)	(0.5465)
Observations	552	552	552	552	552	552	552	511	511	511
R^2 (2nd stage)	0.773	0.118	0.091	0.171	0.649	0.610	0.627	0.765	0.788	0.790
Kleibergen-Paap rk Wald F-Statistic	23.266	48.171	9.497	9.705	329.441	54.926	57.674	56.467	20.333	21.828
Number of States	23	23	23	23	23	23	23	23	23	23
Own Price Elasticity	-1.159	-1.244	1.257	1.217*	-0.645*	0.321	0.195	-2.653***	-2.203**	-2.239**
	(0.8766)	(0.9398)	(0.7870)	(0.7311)	(0.3378)	(0.7768)	(0.7902)	(0.4810)	(0.8917)	(0.9123)
Cigarette Cross-Tax Elasticity	0.185		-0.898*	-0.990*		-0.486	-0.442		0.534	0.551
	(0.4444)		(0.5429)	(0.5221)		(0.3715)	(0.3902)		(0.4836)	(0.4707)

*** p <0.01, ** p<0.05, * p<0.1
Robust standard errors in parenthesis, standard errors are clustered at the state level. Price and tax elasticities are calculated at the means using the margins command from STATA 17

6. Discussion

We estimated the demand for e-cigarette products at different nicotine concentrations, products with less than 3% nicotine, between 3 and 5% nicotine, and greater than or equal to 5% nicotine. Our results suggest that nicotine concentration in e-cigarettes is an important feature, which affects the demand for e-cigarettes. Our analysis shows that starting in 2017 and working up to the last quarter of 2021, the number of e-cigarette products with greater than 5% nicotine concentration rapidly increased – vastly increasing the number of available substitute goods for consumers. As economic theory would predict, this increase in competition led to decreases in prices, and provided consumers with closer substitute products and options, thus making these higher nicotine concentrated products more price elastic. We ran numerous models and found that our estimates are very robust to specification, suggesting that our estimates are unbiased. The results of this study expand our understanding of how the e-cigarette market functions, and empirically demonstrates how the elasticity of demand becomes larger in absolute terms as products that are close substitutes to one another become more available.

We find that our elasticity of demand for the entirety of the e-cigarette market is consistent with previous studies. Our estimates range from -2.117 to -1.494, with the former being in line with a recent estimate of -2.2 published by Cotti et al.[43] and the latter being within the confidence intervals of the price elasticity of -1.3 calculated by Allcot and Rafkin.[48] When compared to previous studies using store scanner data compiled by the Nielsen Company from 2009 through 2012, Huang et al. estimated own price elasticities for disposable e-cigarettes centered around −1.2, while those for reusable e-cigarettes were approximately −1.9.[49] Using more years of Nielsen Retail Scanner data (2007-2014), Huang and colleagues (2018) estimated the own-price elasticity for disposable and reusable e-cigarettes to be −1.6 and −1.4, respectively. [56] Zheng et al. (2017) used 2009–2013 Nielsen Retail Scanner data to estimate a price elasticity of demand for all e-cigarettes and concluded that own-price elasticity of e-cigarettes sales was −2.1. [57]

While these previous findings imply that e-cigarettes are price elastic, our findings show that elasticities of demand vary substantially when broken down by nicotine concentration. For products with few substitutes, such as those with nicotine concentrations of less than 5% (our first and second group categorizations), elasticities of demand are more inelastic ranging from -0.858 to -0.536. For products with many close substitutes, such as those with the highest nicotine concentration of 5% and greater, elasticities of demand are more elastic ranging from -1.837 to -1.316.

We also find that products with the lowest nicotine concentration may be economic complements to products with the highest nicotine concentration and vice-versa. To our knowledge we are the first to show this dynamic within the e-cigarette market. Since we used sales data, we are unable to test this finding with actual e-cigarette consumers. However, we believe this finding is consistent with other research showing that more than half of past 30-day users tend to use multiple e-cigarette devices concurrently. [58,59] Moreover, our findings further reinforce the knowledge that different nicotine concentrations target different preferences within a product user. For example, e-cigarette users who are interested in making "big vapor clouds" prefer e-cigarettes with lower nicotine levels, while those seeking a stronger "throat hit" lean towards products with higher nicotine strength. [60]

Past research has found mixed results on whether e-cigarettes and cigarettes may be substitute goods. [48–55,61,62] We find only weak evidence of economic substitution. There are two reasons that may explain our finding. First, previous researchers that have not controlled for nicotine strength in their models may have identified an erroneous finding. This may explain why some papers find mixed results, [49,53,55], some find that e-cigarettes and cigarettes are substitutes [50,52] and others find that they may be complementary goods. [54,63] Second, e-cigarettes and cigarettes may at one time have been economic substitutes, as this was their intent. However, over time it is possible that each product has found a unique consumer base, and users see e-cigarettes and cigarettes as two distinct products. This may be the case with daily tobacco youth and young adult users, who tend to use a primary product. [64] Future research should more closely examine the relationship between cigarettes, other tobacco products, and products such as alcohol and cannabis that may be concurrently used while controlling for e-cigarette nicotine strength.

Our study has many strengths but it is not without limitations. First, our findings are limited by the availability of our retail sales data, which is restricted to 23 states, and does not capture online sales or those from independent vape shops. Online sales and those from independent vape shops are estimated to account for approximately 20-30% of all e-cigarette sales. [31] Had we been able to include online and independent vape shop sales we may have estimated elasticities of demand that were less specific to convenience store sales, as upwards of 96% of our retail sales data are from convenience stores. It is unclear if online and independent vape stores sell more products within a specific nicotine concentration category. Second, since we use retail sales data, we are not able to make inference on who is using e-cigarettes of different nicotine concentration, how these products are used, if more than one product is used concurrently or the intensity of use. Given that elasticities of demand also differ based on income, making youth more sensitive to changes in prices, [65] we would expect further differences based on both user profiles and nicotine concentration.

7. Conclusion

Our study finds that in a rapidly evolving e-cigarette market, demand for e-cigarettes varies considerably by nicotine strength. Demand for high nicotine products with many close substitutes is much more responsive to price changes compared to lower nicotine strength products that have fewer alternatives. Our evidence also suggests that e-cigarettes with the lowest and highest nicotine concentration may be economic complements, implying that consumers may concurrently use e-cigarettes of different nicotine concentrations.

Disclaimer

The conclusions drawn from the NielsenIQ data are those of the researcher(s) and do not reflect the views of NielsenIQ. NielsenIQ is not responsible for, had no role in, and was not involved in analyzing and preparing the results reported.

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Availability of data and materials

Due to contractual agreements, data cannot be made available to the public. The data that support the findings of this study are available from NielsenIQ, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of NielsenIQ.

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