Evaluation of alcohol taxes as a public health opportunity to reduce liver transplant listings for alcohol-related liver disease

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Abstract:

Background: Alcohol-related liver disease (ALD) is a leading indication for liver transplantation. **Methods:** State consumption of spirits, wine, and beer was determined from published sources. Excise and ad valorem alcohol taxes of spirits, wine, and beer were calculated following standard practices and correlated using multiple logistic regression models to 2002 to 2015 ALD transplant listing data from the United Network for Organ Sharing database. **Results:** 21.22% (29,161/137,440) of transplant listings were for ALD. Increased consumption of spirits was associated with increased ALD transplant listings (odds ratio [OR]: 1.67; 95% CI: 1.12 to 2.49, $p = 0.01$), but wine and beer consumption did not have a statistically significant association with ALD transplant listings. Spirits excise taxes on- and off-premise were inversely associated with ALD transplant listing (OR: 0.79 and 0.82, respectively, both $p < 0.02$). Beer and wine taxes were not significantly associated with ALD transplant listings. **Conclusions:** Transplant listings for ALD are directly associated with spirit consumption and inversely associated with spirits excise taxes. These findings suggest a possible public health benefit of increasing excise taxes for spirits.

Keywords: alcohol-related liver disease | liver transplantation | alcohol taxes | public health | taxes

Article:

The burden of alcohol-related liver disease (ALD) is increasing. Recent studies report a rising prevalence of ALD among privately insured patients (Mellinger et al., 2018), an increase in the proportion of liver transplants performed for ALD (Lee et al., 2019), and ALD being the leading cause of gastrointestinal disease mortality (Peery et al., 2019). Additionally, patients aged 25 to 34 have been reported to have the greatest increase in cirrhosis-related mortality as a result of increased prevalence of ALD (Tapper and Parikh, 2018). Many patients with ALD have underlying alcohol use disorder (AUD), which is also on the rise. Particularly among women, minorities, and socioeconomically disadvantaged populations, the prevalence of high-risk drinking and AUD is increasing nationwide (Grant et al., 2017). This is particularly concerning as a recent systematic review estimates that all-cause mortality and prevalence of malignancies increase as levels of alcohol consumption increase (GBDA Collaborators, 2018). Furthermore, increases in AUD and ALD vary across different regions of the United States (Dwyer-Lindgren et al., 2015; Haughwout, 2017; Lee et al., 2019). Given the public health concern of the rising burden of AUD and ALD, identification of state strategies to reduce disease is imperative.

One possible strategy involves increasing the alcohol tax. A prior review using alcohol consumption data reported decreases in the consumption of spirits, wine, and beer (1.5, 1.0, and 0.3%, respectively) for every 1% increase in alcohol price (Leung and Phelps, 1993). Recent systematic reviews suggested an inverse correlation between alcohol tax or price with alcohol sales, consumption, and alcohol-related harms (Elder et al., 2010; Wagenaar et al., 2009), though a more recent meta-analysis suggested these inverse correlations may be influenced by significant publication bias (Nelson, 2013). Additionally, when Finland decreased alcohol taxes by an average of 33% in 2004, alcohol-related deaths subsequently increased by 16 and 31% in men and women, respectively, with a disproportionate increase in socioeconomically disadvantaged populations (Herttua et al., 2008). Overall, taxation and price increase appear to inversely affect alcohol consumption and the subsequent development of ALD.

The impact of nationwide differences in alcohol taxes on liver transplant listings has not been studied. Because patients on the liver transplant waiting list are high healthcare utilizers (Shen et al., 2019), understanding the relationship between alcohol tax and liver transplant listings for ALD may provide valuable information for public health and healthcare cost-saving initiatives. In this study, we sought to understand whether changes in alcohol taxes are associated with liver transplant listing due to ALD. We hypothesized that the number of transplant listings for ALD is directly associated with alcohol consumption and inversely associated with alcohol tax rates.

Materials and Methods

ALD Patient-Level United Network for Organ Sharing (UNOS) Data

We used patient-level data from the UNOS database, which contains prospectively collected demographic and disease severity data on all patients listed for liver transplantation in the United States. We studied patients waitlisted from 2003 to 2015 and age ≥14 (n = 139,039) because alcohol consumption-per-capita data at the state level were available over this time period and age-group through the National Institute on Alcohol Abuse and Alcoholism (NIAAA; Haughwout, 2017). The recorded state residency of the patient at the time of liver transplant listing registration was used to assign state per capita alcohol consumption and alcohol taxes in

the analysis. We removed patients not registered in the 50 United States and the District of Columbia (n = 1,599) because alcohol consumption-per-capita data were not available outside of these jurisdictions (Haughwout, 2017). The remaining 137,440 patients were included in our analysis.

We created 2 liver transplant waiting list cohorts—ALD and non-ALD—based on the primary diagnosis at time of listing, following procedures previously used by Lee and colleagues (2019) classifying ALD as those with "alcohol-related cirrhosis" (UNOS code 4215) and "acute alcohol-related hepatitis" (UNOS code 4217). We also included patients with a mixed primary diagnosis of "alcohol-related cirrhosis with hepatitis c" (UNOS code 4216). Patients coded as status 1, 1A, and 1B, 3.93% (5,406/137,440) of the studied population, were included in the analysis as 2.44% (132/5,406) were noted to also be coded as having a primary diagnosis of ALD at time of listing. Patients listed for multiple organs (i.e., kidney–liver and heart–liver) were included in the analysis (n = 12,861). Because the majority of transplant centers will not relist a patient that was initially transplanted for ALD who has repeat liver failure due to drinking, patients relisted for liver transplant, 2.59% (n = 3,554) of listings, were included in the analysis in order to capture new diagnoses of ALD in patients with a prior history of liver transplant for other indications, 14.97% (532/3,554) of retransplants included in the analysis.

Alcohol Consumption Data

The NIAAA maintains yearly alcohol consumption-per-capita data categorized by spirits, wine, and beer across the 50 United States and the District of Columbia for persons aged ≥14 (Haughwout, 2017). The NIAAA calculates consumption by using sales data in the form of volume or tax revenue, which is then converted using state tax rates. When sales data are not available, shipment data from beverage industry sources are used (Haughwout et al., 2016). We extracted annual consumption data from 2003 to 2015, correlating alcohol consumption-per-capita data to patient-level UNOS data.

Taxation Calculation

Our approach to alcohol tax derivation followed recommendations put forth by the NIAAA with relevant terms as defined included in Table 1 (Klitzner, 2012; Lucey et al., 2009). Alcohol taxes in this analysis included state-specific excise taxes and ad valorem taxes, both of which subdivided into on-premise and off-premise consumption categories (APIS, 2017; Lucey et al., 2009). Alcohol taxes remained stable throughout the study period (Fig. S1a-c). Of note, the majority of localities assessed did not have ad valorem taxes (Table S1).

Table 1. Definitions for Alcohol Taxes Included in Analysis

Term	Definition
Excise tax	Volume-based alcohol tax calculated based on the *amount* of alcohol sold assuming specific concentrations of alcohol (40% for spirits, 12% for wine, and 5% for beer)
Ad valorem tax	Price-based alcohol tax calculated based on the *price* of alcohol sold
On-premise	Alcohol consumed at site of sale (i.e., bar and restaurant)
Off-premise	Alcohol *not* consumed at site of sale (i.e., purchased from liquor store, grocery store, etc)

Tax Data Inputs

Tax data inputs were derived from the Tax Foundation for control states (Tax Foundation, 2018) or the Alcohol Policy Information System for noncontrol states (APIS, 2017; Table S2). Control states included states that acted as the retailer of distribution themselves, whereas noncontrol states licensed private vendors to operate retail systems of distribution (Lucey et al., 2009). Some states transitioned from control states to noncontrol states during the time period (Table S2). While state excise tax and ad valorem data were available for noncontrol states throughout the time period of analysis (APIS, 2017), data for control states were only available for limited time periods depending on the type of alcohol (2007 to 2013 for spirits and 2009 to 2013 for wine and beer; Tax Foundation, 2018). Additionally, for wine, there were no data available on state excise taxes for the following control states: New Hampshire, Mississippi, Pennsylvania, and Utah.

Statistical Analysis

To evaluate the effect of alcohol taxes and consumption on liver transplant listings for ALD, we approached the analysis from a mediation standpoint, believing that changes in alcohol tax would impact transplant listings for ALD through the pathway of changing alcohol consumption (mediator). We therefore performed 4 types of regressions for spirits, wine, and beer, separately, with clustering at the state level. Using aggregated data, we first performed linear regression of per capita alcohol consumption as a function of state-level tax to assess the relationship between consumption and degree of alcohol taxes. We then assessed patient-level data using logistic regression with liver transplant listing for ALD as a function of state-level consumption and as a function of state-level alcohol taxes. Lastly, we performed patient-level logistic regression for transplant listing for ALD as a function of both consumption and tax. Taken together, these analyses constitute the causal step approach to assessing a mediated relationship (Baron and Kenny, 1986), in our case, the effect of alcohol taxes on ALD transplant listings, as mediated through alcohol consumption. State-by-state correlations between transplant listings for ALD and both consumption and taxes were examined to ensure single states were not overly influencing the overall results. All patient-level regressions were performed controlling for the following prespecified variables known to be different between ALD and non-ALD populations (Grant et al., 2017; Lee et al., 2019): age, sex, race and Hispanic ethnicity, education, employment, and insurance. p values < 0.05 were used as a cutoff for statistical significance. Elasticity analyses, which suggest how changes in alcohol tax subsequently affect the rate of alcohol consumption or liver transplant listing for ALD, were performed for alcohol taxes. We estimated tax elasticities, not price elasticities, and thus, our regression models were intended to support a possible causal link between ALD transplant listings and alcohol taxes.

Sensitivity Analyses

Sensitivity analyses included controlling for the year that the patient was placed on the liver transplant waiting list to account for temporal changes over the study period. Additionally, to ensure study findings were not by chance, we repeated all patient-level logistic regression models with primary listing for hepatitis B as a function of consumption and tax, controlling for the same prespecified predictors indicated above, because we expected listing for hepatitis B to not be affected by alcohol taxes. To evaluate applicability beyond the Medicaid population,

which likely includes more low-income individuals, all multiple regression analyses were repeated with the Medicaid population removed and controlling for all the prespecified variables with the exception of insurance. Additionally, to investigate the effect that differences in state income may have on the analysis, census data were used to estimate the median household income by state and all multiple regression analyses were repeated controlling for median household income. The relationship of consumption and taxes with alcohol-related hepatitis was also explored in sensitivity analysis. Sensitivity analyses were performed to assess the impact of including secondary listing diagnoses of ALD on the findings; patients with either a primary or secondary listing diagnosis of ALD were included in the ALD cohort. All analyses were performed using Stata (StataCorp. 2015. Stata Statistical Software: Release s14. College Station, TX: StataCorp LP).

Institutional Review Board

Our study was found to be exempt from institutional review board (institutional review board protocol #1810019692).

Results

Demographics

Of 137,440 patients listed for liver transplant in the United States between 2003 and 2015, 21.22% (29,161) were for ALD. Compared to non-ALD transplant candidates, ALD candidates were more likely to be men (77.37% vs. 60.94%), White (75.87% vs. 70.03%), and Hispanic (16.74% vs. 13.17%; Table 2). The ALD transplant candidates were also less likely to be employed (13.12% vs. 20.94%) or privately insured (55.23% vs. 59.85%).

Per Capita Alcohol Consumption as a Function of Alcohol Tax Using Aggregated Data

Regression results of per capita alcohol consumption as a function of alcohol taxes suggested an inverse relationship of spirits excise taxes with alcohol consumption (respective regression coefficient for on- and off-premise tax of −0.18 [$p = 0.06$] and −0.16 [$p = 0.09$]), though alcohol consumption as a function of wine or beer excise taxes was not statistically significant (Table S3). The relationships between ad valorem taxes and alcohol consumption were also not statistically significant. In elasticity analysis, for every 1% increase in spirits excise tax, spirit consumption decreased 0.10% on-premise and 0.08% off-premise ($p = 0.07$ and $p = 0.11$; Table 3a; Fig. 1*AB*).

Table 2. Demographics of Alcohol-Related Liver Disease (ALD) and Non–alcohol-Related Liver Disease (non-ALD) Patients Aged ≥ 14 Listed for Liver Transplant (2003 to 2015)

	Alcohol-related liver disease (*n* = 29,161)	**Non–alcohol-related liver disease (*n* = 108,279)**	***p***
Men, *n* (%)	22,562 (77.37)	65,988 (60.94)	<0.01
Age, median (IQR)	54 (49 to 60)	56 (49 to 61)	<0.01
Race and Hispanic ethnicity, *n* (%)			<0.01
White	22,125 (75.87)	75,828 (70.03)	
Black	1,412 (4.84)	11,125 (10.27)	
Hispanic	4,881 (16.74)	14,255 (13.17)	
Asian	351 (1.20)	5,739 (5.30)	
American Indian/Alaskan Native	281 (0.96)	595 (0.55)	
Native Hawaiian/other Pacific Islander	19 (0.07)	202 (0.19)	
Multiracial	92 (0.32)	535 (0.49)	
Laboratory values at time of listing			
Albumin, median (IQR)	3.00 (2.60 to 3.50)	3.00 (2.60 to 3.50)	0.27
Creatinine, median (IQR)	1.05 (0.80 to 1.50)	1.00 (0.79 to 1.40)	<0.01
Sodium, median (IQR)	136 (132 to 139)	137 (134 to 140)	<0.01
Bilirubin, median (IQR)	2.90 (1.60 to 6.10)	2.30 (1.20 to 5.20)	<0.01
INR, median (IQR)	1.50 (1.30 to 1.90)	1.40 (1.20 to 1.70)	<0.01
MELD score[a], median (IQR)	17 (13 to 24)	15 (11 to 22)	<0.01
Highest education level, *n* (%)			<0.01
None	80 (0.27)	387 (0.36)	
Grade school	1,501 (5.15)	4,795 (4.43)	
High school	12,078 (41.42)	41,185 (38.04)	
College or technical	6,005 (20.59)	22,331 (20.62)	
Associate degree or higher	5,128 (17.59)	22,038 (20.35)	
Unknown	4,369 (14.98)	17,543 (16.20)	
Employment, *n* (%)			<0.01
Working	3,825 (13.12)	22,673 (20.94)	
Not working	21,410 (73.42)	68,652 (63.40)	
Unknown	3,926 (13.46)	16,954 (15.66)	
Insurance			<0.01
Private	16,107 (55.23)	64,807 (59.85)	
Medicaid	6,097 (20.91)	15,487 (14.30)	
Medicare	5,142 (17.63)	21,812 (20.14)	
Veterans Affairs	827 (2.84)	2,023 (1.87)	
Other government	702 (2.41)	2,901 (2.68)	
Other self	286 (0.98)	1,231 (1.14)	
Unknown	0 (0.00)	18 (0.02)	

INR, international normalized ratio; MELD, model for end-stage liver disease

[a] This is referring to the MELD and not the MELDNa.

Table 3. Elasticity Tax Results for (a) Regression of Per Capita Alcohol Consumption as a Function of Excise and Ad Valorem Tax for Spirits, Wine, and Beer, (b) Multiple Regression of Listing for Alcohol-Related Liver Disease as a Function of Excise and Ad Valorem Taxes for Spirits, Wine, and Beer, (c) Multiple Regression of Listing for Alcohol-Related Liver Disease as a Function of Alcohol Consumption And Excise and Ad Valorem Taxes for Spirits, Wine, and Beer[a]

	On-premise			Off-premise		
	Elasticity	**95% CI**	***p***	**Elasticity**	**95% CI**	***p***
(a) Regression of Per Capita Alcohol Consumption						
Spirits						
Excise tax	−0.10	−0.20, 0.01	0.07	−0.08	−0.18, 0.02	0.11
Ad valorem tax	−0.02	−0.22, 0.18	0.86	0.08	−0.16, 0.32	0.51
Wine						
Excise tax	−0.03	−0.17, 0.12	0.68	−0.04	−0.18, 0.11	0.60
Ad valorem tax	−0.04	−0.20, 0.13	0.63	−0.07	−0.27, 0.13	0.49
Beer						
Excise tax	−0.00	−0.03, 0.03	0.82	−0.01	−0.04, 0.02	0.52
Ad valorem tax	0.02	−0.11, 0.15	0.75	−0.08	−0.23, 0.08	0.33
(b) Function of excise						
Spirits						
Excise tax	−0.07	−0.13, −0.01	0.02	−0.06	−0.12, −0.01	0.02
Ad valorem tax	−0.01	−0.03, 0.02	0.50	0.01	−0.02, 0.04	0.47
Wine						
Excise tax	−0.03	−0.08, 0.02	0.22	−0.03	−0.07, 0.02	0.22
Ad valorem tax	0.00	−0.02, 0.02	0.97	0.01	−0.02, 0.05	0.43
Beer						
Excise tax	−0.05	−0.11, 0.01	0.10	−0.05	−0.10, 0.01	0.08
Ad valorem tax	−0.00	−0.02, 0.02	0.94	−0.00	−0.04, 0.03	0.83
(c) Function of Alcohol Consumption And Excise						
Spirits						
Excise tax	−0.05	−0.10, 0.00	0.05	−0.05	−0.10, −0.00	0.05
Ad valorem tax	0.00	−0.02, 0.02	0.91	0.01	−0.02, 0.03	0.66
Wine						
Excise tax	−0.03	−0.07, 0.02	0.23	−0.03	−0.07, 0.01	0.17
Ad valorem tax	0.01	−0.02, 0.04	0.52	0.02	−0.01, 0.05	0.20
Beer						
Excise tax	−0.05	−0.11, 0.01	0.08	−0.05	−0.10, 0.01	0.08
Ad valorem tax	−0.01	−0.03, 0.02	0.66	0.00	−0.04, 0.04	0.99

[a] Age, sex, race and Hispanic ethnicity, education, employment, and insurance were controlled for in multiple regression analysis. Clustering was conducted at the state level.

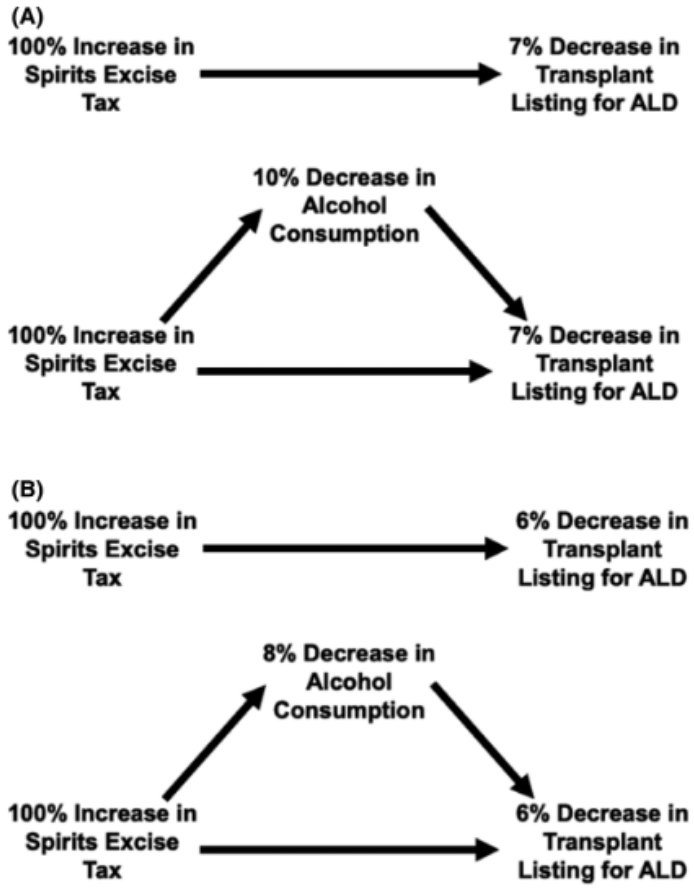

Fig. 1. Change in spirits excise tax on- (**A**) and off-premise (**B**) decrease transplant listing for alcohol-related liver disease (ALD) through mediation (alcohol consumption).

Liver Transplant Listing for ALD as a Function of Alcohol Consumption

In multiple regression modeling controlling for prespecified variables, spirits consumption correlated with more liver transplant listings (odds ratio [OR]: 1.67; 95% CI: 1.12 to 2.49, $p = 0.01$). Wine consumption also correlated with more transplant listings though this relationship was not statistically significant (OR: 1.40; 95% CI: 0.98 to 2.00, $p = 0.07$). Beer consumption was not clearly correlated with liver transplant listings (OR: 1.30; 95% CI: 0.82 to 2.04, $p = 0.26$; Tables 4a and S4a).

Liver Transplant Listing for ALD as a Function of Alcohol Tax Using Patient-Level Liver Transplant Waitlist Data and State-Level Taxation Data

Higher spirits excise taxes were associated with fewer ALD liver transplant listings in multiple regression analyses (OR: 0.79; 95% CI: 0.65 to 0.96, $p = 0.02$ for on-premise spirits excise taxes; OR: 0.82; 95% CI: 0.69 to 0.97, $p = 0.02$ for off-premise spirits excise taxes; Tables 4b and S4b). Multiple regression analyses of beer excise taxes, wine excise taxes, and ad valorem taxes for all alcohol were not significantly associated with transplant listing for ALD (Tables 4b and S4b). Elasticity analyses suggested that for every 1% increase in spirits excise

tax, transplant listing for ALD decreased 0.07 and 0.06% on- and off-premise, respectively (both $p = 0.02$; Table 3b; Fig. 1*AB*).

Table 4. Multiple Regression Results of Liver Transplant Listing for Alcohol-Related Liver Disease as a Function of (a) Per Capita Alcohol Consumption, (b) Excise and Ad Valorem Taxes, (c) Per Capita Consumption and Excise and Ad Valorem Taxes for Spirits, Wine, and Beer[a]

	OR	95% CI	*p*
(a) Per capita alcohol consumption			
Consumption			
Spirits	1.67	1.12, 2.49	0.01
Wine	1.40	0.98, 2.00	0.07
Beer	1.30	0.82, 2.04	0.26

	On-premise			Off-premise		
	OR	**95% CI**	***p***	**OR**	**95% CI**	***p***
(b) Excise and Ad Valorem Taxes						
Spirits						
Excise tax	0.79	0.65, 0.96	0.02	0.82	0.69, 0.97	0.02
Ad valorem tax	0.95	0.82, 1.10	0.50	1.08	0.89, 1.30	0.47
Wine						
Excise tax	0.41	0.10, 1.73	0.22	0.44	0.12, 1.62	0.22
Ad valorem tax	1.00	0.86, 1.16	0.97	1.09	0.89, 1.33	0.42
Beer						
Excise tax	0.04	0.00, 1.73	0.10	0.04	0.00, 1.53	0.08
Ad valorem tax	1.00	0.87, 1.14	0.94	0.98	0.78, 1.23	0.83
(c) Per capita consumption and excise and ad valorem taxes						
Spirits						
Alcohol consumption	1.73	1.14, 2.63	0.01	1.72	1.11, 2.65	0.02
Excise tax	0.85	0.72, 1.00	0.05	0.85	0.72, 0.99	0.04
Ad valorem tax	1.01	0.88, 1.15	0.91	1.04	0.89, 1.20	0.65
Wine						
Alcohol consumption	1.51	0.95, 2.40	0.08	1.49	0.98, 2.27	0.06
Excise tax	0.44	0.11, 1.67	0.23	0.44	0.13, 1.44	0.17
Ad valorem tax	1.06	0.89, 1.25	0.52	1.14	0.94, 1.37	0.19
Beer						
Alcohol consumption	1.30	0.79, 2.11	0.30	1.27	0.80, 2.03	0.31
Excise tax	0.04	0.00, 1.47	0.08	0.04	0.00, 1.46	0.08
Ad valorem tax	0.97	0.83, 1.13	0.66	1.00	0.79, 1.26	0.99

[a] Age, sex, race and Hispanic ethnicity, education, employment, and insurance were controlled for in multiple regression analysis. Clustering was conducted at the state level.

Liver Transplant Listing for ALD as a Function of Both Tax and Consumption Using Patient-Level Liver Transplant Waitlist Data and Both State-Level Taxation and Consumption Data

Multiple regression analyses including both consumption and taxation variables were conducted without substantial effect on multiple regression consumption or excise tax off-premise; spirits consumption and excise tax off-premise remained statistically significant. Spirits excise taxes are associated with lower ALD liver transplant listings (OR: 0.85; 95% CI: 0.72 to 1.00, $p = 0.05$ for

on-premise excises taxes; OR: 0.85; 95% CI: 0.72 to 0.99, $p = 0.04$ for off-premise excise taxes; Tables 4c and S4c). Elasticity analyses suggested that for every 1% increase in spirits excise taxes, transplant listings for ALD decreased by 0.05% ($p = 0.05$; for both on-premise and off-premise taxes; Table 3c).

Sensitivity Analyses

Study results were not significantly affected when accounting for temporal changes (Table S5a-c). When removing the Medicaid population from the analysis (Table S6a-c), wine consumption was significantly associated with listing for ALD (OR: 1.51; 95% CI: 1.07 to 2.14, $p = 0.02$; Table S6a), and this remained significant when assessing ALD as a function of both wine consumption and wine taxes (Table S6c). By accounting for the median household income, beer consumption was significantly associated with transplant listing for ALD (OR: 1.63; 95% CI: 1.07 to 2.47, $p = 0.02$; Table S7a), and this remained statistically significant when assessing ALD as a function of both beer consumption and beer taxes (Table S7c). Statistically significant associations were not observed for primary liver transplant listing for hepatitis B ($n = 3,751$, this included patients with a secondary listing diagnosis of ALD, 2.88% [108/3,751]) as a function of alcohol consumption and/or tax (Table S8a-c). Greater spirits excise taxes were associated with decreased listing for alcohol-related hepatitis (adjusted ORs < 1 with $p < 0.05$; Table S9). A minority of patients, 22.14% ($n = 30,435$), had a secondary listing diagnosis coded, of which 15.26% (4,645/30,435) were for ALD. When using a primary or secondary listing diagnosis of ALD to categorize patients into the study ALD cohort, similar findings as reported in the main analysis were observed (Table S10).

Discussion

ALD is a leading indication for liver transplant listing nationally and internationally (Lee et al., 2019), and identifying actionable public health policies that may reduce disease burden is imperative. Our findings suggested that changes in taxation policies on spirits excise taxes could reduce consumption and listing for liver transplantation; for every 100% increase in spirits excise taxes, per capita spirit consumption decreased by 8 to 10% and transplant listing for ALD decreased by 7 to 6% (on-premise and off-premise, respectively; Fig. 1*AB*).

As an example, in 2015, the highest per capita spirits consumption reported for a noncontrol state occurred in Delaware with 1.75 gallons of spirits per capita, an excise tax of $3.75/gallon, and transplant listing for ALD accounting for 27.9% (19/68) of all transplant listings. If spirits excise taxes increased by 100% (i.e., $7.50/gallon), then based on our modeling results, per capita alcohol consumption would decrease by 10 and 8% (on-premise and off-premise, respectively) and transplant listing for ALD would decrease by ≥6% (i.e., 14/68 instead of 19/68 patients would be listed for liver transplant due to ALD). Across all alcohol and tax specifications, our tax elasticity estimates were smaller than the previously estimated −0.30 to −0.50 price elasticity (Nelson, 2013; Wagenaar et al., 2009), meaning that relatively large changes in excise tax would be necessary to have clinical impact. Nevertheless, given the rising burden of ALD and the limited resource of liver organ transplantation, all modifiable policies should be considered and explored.

Although ALD is a major indication for liver transplantation, only a small proportion of patients with ALD require transplantation. Most patients improve with abstinence and do not require enrollment on the waitlist. For patients with ALD not requiring transplantation, we suspect that increasing alcohol taxes would decrease clinical interventions needed to encourage abstinence, which could potentially decrease healthcare costs, preventing early disease progression and mortality. Evidence supporting this in prior publications includes increases in alcohol taxes in Florida from 1969 to 2004 resulting in significant reductions in alcohol-related mortality (Maldonado-Molina and Wagenaar, 2010).

While our analyses specifically assessed the effectiveness of alcohol taxes, minimum unit pricing has also previously been proposed in many countries as a means to disincentivize alcohol use. However, minimum unit pricing is controversial as it may disproportionately affect the poor and responsible drinkers with less alcohol consumption. Whereas some data exist suggesting that minimum unit pricing may reduce consumption in harmful drinkers, other data contradict this finding (Holmes et al., 2014; Sharma and Vandenberg, 2019). Currently, in the United States, there are no state- or federal-level minimum unit pricing policies for alcohol. Given the heterogenous data on the effectiveness of minimum unit pricing, alcohol taxes seem to be a more viable option for impacting alcohol consumption.

Prior studies suggested that changes in alcohol tax affected alcohol prices, with a greater observed effect on spirit and wine prices than on beer prices (Kenkel, 2005). This may explain why changes in spirit taxation are associated with consumption and listing for ALD, more so than beer and wine taxation. The lack of a statistically significant association with wine may be due to relationships between socioeconomic status and alcohol beverage preference. National surveys performed by Gallup from a random sample of over 1,000 adults in 2015 indicated that respondents with higher household incomes (≥$75,000) were more likely to prefer wine than those with lower household incomes (<$30,000), 38% vs. 29%, respectively (Jones, 2015), and in sensitivity analysis, with the Medicaid population removed, a statistically significant relationship between wine consumption and transplant listing for ALD was observed (Table S6). Therefore, while taxation changes may have greater price effects on spirits and wine, the higher socioeconomic status of wine drinkers may negate or require even higher tax and price changes to observe consumption and ALD transplant listing effects.

Our alcohol consumption results support a possible link between spirit excise taxes and transplant listing for ALD. Our findings are consistent with those for clinical outcomes other than liver transplantation. Prior analysis investigating the relationship of spirits, wine, and beer taxation on cirrhosis mortality identified that increased spirits taxes significantly are associated with decreased cirrhosis mortality while beer and wine taxes were insignificant (Ponicki and Gruenewald, 2006). A systematic review and meta-analysis suggested that doubling alcohol tax could profoundly impact mortality and morbidity, reducing alcohol-related mortality (35%) sexually transmitted diseases (6%), violence (2%), and crime (1.4%; Wagenaar et al., 2010). Additionally, in other populations, alcohol taxes have been shown to have an inverse relationship with alcohol-related injury (Naimi et al., 2018). Thus, taxation and subsequent price changes represent an important public health opportunity to consider for reducing alcohol-related morbidity and mortality.

Other modeling studies reporting on the influence of taxation changes on detrimental health habits similarly found that sizable increases in tobacco taxes were required to have significant clinical effect. A 100% increase in tobacco tax was required to decrease adult smoking by about 5% (Kevin and Robert, 2012), which was similar to our finding that a 100% increase in spirits excise tax was required to decrease transplant listing for ALD by ≥6.3%. Further supportive of these results, increased cigarette tax in California in 2017, which increased the price for a pack of cigarettes from an average of $6 to $9, resulted in decreased cigarette sales by 23% (Levin, 2017).

Our study has several limitations involving consumption, taxation, and UNOS data.

Consumption Limitations

Potential influences that may have impacted alcohol consumption that was not accounted for in NIAAA consumption data included state policies, cross-border sales, illicit production of alcohol, and variation in state reporting of alcohol sales. Additionally, the data set lacked details of the patients' alcohol consumption behaviors and underlying AUD history that could have offered further insight into the relationships among the different taxes, per capita consumption patterns, and transplant listing for ALD. While the details of alcohol consumption leading to disease were unknown, given the stability of taxes over time (Fig. S1a-c), the current tax at time of listing was likely experienced by the studied patient population over several years, capturing the impact of tax on alcohol consumption.

Taxation Limitations

The data for control states were incomplete, restricting analysis to only those years in which control states reported alcohol taxes (2007 to 2013 for spirits and 2009 to 2013 for wine and beer). Though our study did not include data on alcohol pricing, prior literature suggests that a 10% increase in excise taxes results in a 10 to 20% increase in price, suggesting that using tax increases as a surrogate of price increases is reasonable (CAMYJHU, 2017; Kenkel, 2005; Nelson and Moran, 2019; Young and Bielińska-Kwapisz, 2002).

UNOS Data Limitations

Listing on the liver transplant waitlist is affected by many factors including regional and or transplant center biases, degree of social support, and nonliver comorbidities, which were unable to be controlled for in our analyses. Because patients' state residency at time of listing was used to assign alcohol consumption and taxation data, patients that spent the majority of their life in a different state could have been inaccurately categorized. While the impact of this on the data analysis is unknown, this likely would have impacted the ALD and non-ALD cohorts equally. Additionally, publicly or self-insured populations were less likely to be evaluated for liver transplant listing (Bryce et al., 2009); therefore, lack of significant findings for wine and beer taxation changes may be due to the population studied, even though analyses were controlled for education and employment. Because liver disease can be multifactorial, patients with mixed ALD etiologies other than HCV-ALD may have been coded as non-ALD, although there was no reason to believe that there were geographic differences in this possible undercoding.

Despite these limitations, strengths of the study included the incorporation of both state excise taxes and ad valorem taxes in the approach to taxation calculation, the 13-year time period studied, and the incorporation of national data.

Our study suggests the opportunity for increasing alcohol taxes, particularly spirits excise taxes, to reduce alcohol consumption and transplant listing for ALD. Measures to address transplant listing for ALD are imperative given the rise in these transplant listings and the limited availability of organs. Our findings are consistent with other studies indicating that significant increases in alcohol taxation may have clinical and societal benefits.

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Conflict of interest

No authors have anything to disclose.

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Supplementary Tables:

Supplementary Table 1:

1a) Spirits ad valorem tax values and frequency for on- and off-premise tax

Spirits Ad Valorem Tax					
Ad valorem tax on-premise	**Frequency**	**Percent (%)**	**Ad valorem tax off-premise**	**Frequency**	**Percent (%)**
0	523	78.88	0	562	84.77
.0151	1	0.15	.0151	1	0.15
.02	26	3.92	.0167	1	0.15
.025	13	1.96	.017	2	0.30
.0257	1	0.15	.0177	1	0.15
.03	4	0.60	.0185	1	0.15
.04	3	0.45	.02	26	3.92
.0405	1	0.15	.0219	1	0.15
.0418	1	0.15	.025	13	1.96
.0425	8	1.21	.02592	1	0.15
.05	13	1.96	.027	7	1.06
.0775	11	1.66	.03	17	2.56
.087	2	0.30	.0325	6	0.90
.09	2	0.30	.0343	1	0.15
.1015	1	0.15	.04	3	0.45
.11	10	1.51	.0405	1	0.15
.1164	1	0.15	.0425	2	0.30
.117	2	0.30	.09	2	0.30
.1178	2	0.30	.1017582	1	0.15
.1219	1	0.15	.1087363	1	0.15
.127	7	1.06	.11	9	1.36
.14	10	1.51	.41	4	0.60
.15	13	1.96			
.16	3	0.45			
.407	4	0.60			

1b) Wine ad valorem tax values and frequency for on- and off-premise tax

Wine Ad Valorem Tax					
Ad valorem tax on-premise	**Frequency**	**Percent (%)**	**Ad valorem tax off-premise**	**Frequency**	**Percent (%)**
0	542	81.75	0	568	85.67
.0151648	1	0.15	.0151648	1	0.15
.02	26	3.92	.0167308	1	0.15
.025	13	1.96	.017	2	0.30
.03	4	0.60	.0177582	1	0.15
.04	15	2.26	.0185	1	0.15
.040625	1	0.15	.02	26	3.92
.041875	1	0.15	.021945	1	0.15
.0425	7	1.06	.025	13	1.96
.0475	1	0.15	.027	6	0.90
.075	13	1.96	.03	18	2.71

.09	2	0.30	.031875	1	0.15
.1017582	1	0.15	.0325	6	0.90
.107	1	0.15	.0350549	1	0.15
.1087363	1	0.15	.04	1	0.15
.11	9	1.36	.040625	1	0.15
.116365	1	0.15	.0425	2	0.30
.117	2	0.30	.09	2	0.30
.117758	1	0.15	.1017582	1	0.15
.1185	1	0.15	.1087363	1	0.15
.121945	1	0.15	.11	9	1.36
.127	6	0.90			
.15	13	1.96			

1c) Beer ad valorem tax values and frequency for on- and off-premise tax

Beer Ad Valorem Tax					
Ad valorem tax on-premise	**Frequency**	**Percent (%)**	**Ad valorem tax off-premise**	**Frequency**	**Percent (%)**
0	543	81.90	0	569	85.82
.01516	1	0.15	.01	8	1.21
.02	23	3.47	.01516	1	0.15
.02125	1	0.15	.01673	1	0.15
.025	15	2.26	.017	2	0.30
.03	4	0.60	.0177582	1	0.15
.04	15	2.26	.0185	1	0.15
.040625	1	0.15	.019945	1	0.15
.041875	1	0.15	.02	13	1.96
.0425	8	1.21	.021945	1	0.15
.04747	1	0.15	.025	13	1.96
.0775	11	1.66	.027	7	1.06
.0840659	1	0.15	.03	9	1.36
.087	2	0.30	.031868	1	0.15
.09	2	0.30	.0325	6	0.90
.1017582	1	0.15	.0350549	1	0.15
.1087363	1	0.15	.04	1	0.15
.11	9	1.36	.04063	1	0.15
.11676	1	0.15	.0425	2	0.30
.117	2	0.30	.0840659	1	0.15
.11775	1	0.15	.09	2	0.30
.1185	1	0.15	.1017582	1	0.15
.12194	1	0.15	.1087363	1	0.15
.127	7	1.06	.11	9	1.36
.17	10	1.51	.17	10	1.51

Supplementary Table 2: Tabular representation of control states

	Spirits	Wine	Beer
Alabama (AL)*	✓	✓	
Alaska (AK)			
Arizona (AZ)			
Arkansas (AR)			
California (CA)			
Colorado (CO)			
Connecticut (CT)			
Delaware (DE)			
District of Columbia (DC)			
Florida (FL)			
Georgia (GA)			
Hawaii (HI)			
Idaho (ID)	✓	✓	
Illinois (IL)			
Indiana (IN)			
Iowa (IA)	✓		
Kansas (KS)			
Kentucky (KY)			
Louisiana (LA)			
Maine (ME)	✓	✓	
Maryland (MD)			
Massachusetts (MA)			
Michigan (MI)	✓		
Minnesota (MN)			
Mississippi (MS)	✓	✓	
Missouri (MO)			
Montana (MT)	✓	✓	
Nebraska (NE)			
Nevada (NV)			
New Hampshire (NH)	✓	✓	
New Jersey (NJ)			
New Mexico (NM)			
New York (NY)			
North Carolina (NC)	✓		
North Dakota (ND)			
Ohio (OH)	✓		
Oklahoma (OK)			
Oregon (OR)	✓	✓	
Pennsylvania (PA)	✓	✓	
Rhode Island (RI)			
South Carolina (SC)			
South Dakota (SD)			
Tennessee (TN)			
Texas (TX)			

Utah (UT)	✓	✓	✓14
Vermont (VT)	✓		
Virginia (VA)	✓	✓	
Washington (WA)*	✓	✓	✓
West Virginia (WV)	✓	✓	
Wisconsin (WI)			
Wyoming (WY)	✓	✓	

*The following were control states but not for the entire period studied: 1) Alabama was a control state for wine from 2/20/2004 to 1/1/2018. 2) Washington was a control state for spirits, wine and beer from 1/1/2003-12/7/2011.((APIS), 2017)

Supplementary Table 3: Regression results of per capita alcohol consumption as a function of excise and ad valorem tax for spirits, wine, and beer*

	On-premise			Off-premise		
	Coef	**95% CI**	***p***	**Coef**	**95% CI**	***p***
Spirits						
Excise tax	-0.18	-0.37, 0.01	0.06	-0.16	-0.34, 0.03	0.09
Ad valorem tax	-0.018	-0.22, 0.18	0.86	0.08	-0.16, 0.32	0.51
Wine						
Excise tax	-0.20	-1.17, 0.77	0.68	-0.26	-1.22, 0.70	0.59
Ad valorem tax	-0.04	-0.20, 0.13	0.63	-0.07	-0.27, 0.13	0.49
Beer						
Excise tax	-0.18	-1.81, 1.45	0.82	-0.52	-2.13, 1.09	0.52
Ad valorem tax	0.02	-0.11, 0.15	0.75	-0.08	-0.23, 0.08	0.33

Coef=Coefficient

*The sample size for spirits, wine, and beer was 559, 541, and 646 state/year observations with 47 clusters for wine and 51 clusters for spirits and beer

Supplementary table 4a: Multiple regression of listing for alcohol-related liver transplant for spirits, wine and beer as a function of alcohol consumption

	Spirits			Wine			Beer		
	OR	**SE**	***p***	**OR**	**SE**	***p***	**OR**	**SE**	***p***
Alcohol consumption	1.67	.34	.01	1.40	.25	.07	1.30	.30	.26
Sex									
Women (ref)									
Men	2.31	.11	<.01	2.30	.11	<.01	2.31	.11	<.01
Age	1.00	.00	<.01	1.00	.00	<.01	1.00	.00	<.01
Race and Hispanic ethnicity									
White (ref)									
Black	.43	.03	<.01	.43	.02	<.01	.43	.02	<.01
Hispanic	1.09	.09	.28	1.06	.08	.46	1.09	.08	.26
Asian	.20	.02	<.01	.19	.02	<.01	.20	.02	<.01
American Indian/Alaskan Native	1.58	.17	<.01	1.62	.18	<.01	1.60	.17	<.01
Native Hawaiian/other Pacific Islander	.29	.08	<.01	.28	.08	<.01	.29	.08	<.01
Multiracial	.58	.10	<.01	.57	.10	<.01	.58	.10	<.01
Highest education level									
None (ref)									
Grade school	1.29	.19	.08	1.28	.19	.09	1.29	.19	.09
High school	1.29	.21	.12	1.29	.21	.11	1.29	.20	.11
College	1.25	.20	.16	1.26	.20	.15	1.26	.20	.14
Associate or higher	1.15	.16	.32	1.16	.16	.30	1.17	.16	.27
Unknown	1.20	.21	.28	1.19	.21	.31	1.17	.21	.36
Employment									
Unemployed (ref)									
Working	.52	.02	<.01	.52	.01	<.01	.51	.02	<.01
Insurance									
Private (ref)									
Medicaid	1.47	.07	<.01	1.48	.07	<.01	1.49	.07	<.01
Medicare	.79	.02	<.01	.79	.02	<.01	.79	.02	<.01
VA	1.28	.11	.01	1.30	.11	.00	1.29	.11	.00
Other government	1.01	.06	.88	1.01	.06	.85	1.01	.06	.91
Other self	.99	.11	.89	1.00	.11	.99	1.01	.11	1.00

Supplementary table 4b: Multiple regression of listing for alcohol-related liver transplant on- and off premise for spirits, wine and beer as a function of tax

	Spirits						Wine						Beer					
	On-premise			Off-premise			On-premise			Off-premise			On-premise			Off-premise		
	OR	SE	*p*	OR	SE	*p*	OR	SE	*p*	OR	SE	*p*	OR	SE	*p*	OR	SE	*p*
Tax																		
Excise	.79	.08	.02	.82	.07	.02	.41	.30	.22	.44	.29	.22	.04	.08	.10	.04	.08	.08
Ad valorem	.95	.07	.50	1.08	.11	.47	1.00	.08	.97	1.09	.11	.42	1.00	.07	.94	.98	.12	.83
Sex																		
Women (ref)																		
Men	2.31	.12	<.01	2.32	.12	<.01	2.36	.11	<.01	2.36	.11	<.01	2.31	.11	<.01	2.31	.11	<.01
Age	1.00	.00	.00	1.00	.00	<.01	1.00	.00	.00	1.00	.01	<.01	1.00	.00	<.01	1.00	.00	<.01
Race and Hispanic ethnicity																		
White (ref)																		
Black	.43	.03	<.01	.42	.03	<.01	.42	.03	<.01	.42	.03	<.01	.43	.03	<.01	.43	.03	<.01
Hispanic	1.07	.09	.41	1.08	.09	.37	1.08	.08	.33	1.09	.08	.29	1.07	.08	.37	1.07	.08	.39
Asian	.19	.02	<.01	.19	.02	<.01	.19	.02	<.01	.19	.02	<.01	.20	.02	<.01	.20	.02	<.01
American Indian/Alaskan Native	1.58	.19	<.01	1.57	.18	<.01	1.63	.20	<.01	1.62	.19	<.01	1.57	.17	<.01	1.57	.17	<.01
Native Hawaiian/other Pacific Islander	.27	.08	<.01	.27	.08	<.01	.28	.08	<.01	.28	.08	<.01	.28	.08	<.01	.27	.08	<.01
Multiracial	.58	.10	<.01	.58	.10	<.01	.57	.11	.00	.57	.11	<.01	.58	.10	<.01	.58	.10	<.01
Highest education level																		
None (ref)																		
Grade school	1.29	.19	.09	1.29	.19	.09	1.29	.19	.08	1.30	.19	.08	1.27	.19	.11	1.27	.19	.11
High school	1.30	.22	.11	1.31	.22	.11	1.30	.21	.11	1.31	.21	.10	1.28	.21	.13	1.28	.20	.13
College	1.27	.21	.15	1.28	.21	.15	1.27	.21	.15	1.27	.21	.15	1.26	.20	.15	1.26	.20	.16
Associate or higher	1.19	.17	.24	1.19	.17	.24	1.18	.17	.23	1.18	.17	.23	1.16	.16	.28	1.16	.16	.28
Unknown	1.22	.23	.29	1.22	.23	.30	1.20	.22	.31	1.20	.22	.32	1.18	.20	.32	1.18	.20	.33
Employment																		
Unemployed (ref)																		
Working	.51	.02	<.01	.51	.02	<.01	.51	.02	<.01	.51	.02	<.01	.52	.01	<.01	.52	.02	<.01
Insurance																		
Private (ref)																		
Medicaid	1.46	.07	<.01	1.47	.07	<.01	1.50	.08	<.01	1.49	.08	<.01	1.47	.07	<.01	1.47	.07	<.01
Medicare	.80	.02	<.01	.80	.02	<.01	.79	.02	<.01	.79	.02	<.01	.79	.02	<.01	.79	.02	<.01
VA	1.22	.10	.01	1.22	.10	.02	1.22	.10	.01	1.22	.10	.02	1.29	.12	<.01	1.29	.12	<.01
Other government	1.05	.07	.48	1.05	.07	.49	1.03	.07	.65	1.03	.07	.67	1.01	.06	.92	1.01	.06	.91
Other self	1.01	.12	.92	1.01	.12	.97	1.03	.12	.79	1.02	.12	.84	1.00	.11	.99	1.00	.11	.99

Supplementary table 4c: Multiple regression of listing for alcohol-related liver transplant on- and off premise for spirits, wine and beer as a function of alcohol consumption and tax

	Spirits						Wine						Beer					
	On-premise			Off-premise			On-premise			Off-premise			On-premise			Off-premise		
	OR	SE	*p*	OR	SE	*p*	OR	SE	*p*	OR	SE	*p*	OR	SE	*p*	OR	SE	*p*
Alcohol consumption	1.73	.37	.01	1.72	.38	.02	1.51	.36	.08	1.49	.32	.06	1.30	.32	.30	1.27	.30	.31
Tax																		
Excise	.85	.07	.05	.85	.07	.04	.44	.30	.23	.44	.27	.17	.04	.07	.08	.04	.08	.08
Ad valorem	1.01	.07	.91	1.04	.08	.65	1.06	.09	.52	1.14	.11	.19	.97	.08	.66	1.00	.12	.99
Sex																		
Women (ref)																		
Men	2.31	.11	<.01	2.31	.11	<.01	2.36	.11	<.01	2.36	.11	<.01	2.31	.11	<.01	2.31	.11	<.01
Age	1.00	.00	<.01	1.00	.00	.00	1.00	.00	.01	1.00	.00	.01	1.00	<.01	<.01	1.00	<.01	<.01
Race and Hispanic ethnicity																		
White (ref)																		
Black	.42	.03	<.01	.42	.03	<.01	.42	.03	<.01	.42	.03	<.01	.44	.02	<.01	.44	.02	<.01
Hispanic	1.09	.09	.28	1.09	.09	.27	1.05	.08	.53	1.06	.08	.44	1.08	.08	.29	1.08	.08	.29
Asian	.19	.02	<.01	.19	.02	<.01	.19	.02	<.01	.19	.02	<.01	.20	.02	<.01	.20	.02	<.01
American Indian/Alaskan Native	1.55	.17	<.01	1.55	.17	<.01	1.64	.19	<.01	1.63	.19	<.01	1.55	.16	<.01	1.55	.16	<.01
Native Hawaiian/other Pacific Islander	.27	.08	<.01	.27	.08	<.01	.27	.08	<.01	.27	.08	<.01	.28	.08	<.01	.28	.08	<.01
Multiracial	.59	.10	<.01	.59	.10	<.01	.57	.10	<.01	.57	.10	<.01	.58	.10	<.01	.58	.10	<.01
Highest education level																		
None (ref)																		
Grade school	1.28	.19	.10	1.28	.19	.09	1.29	.19	.08	1.29	.19	.08	1.27	.19	.11	1.27	.19	.11
High school	1.29	.21	.12	1.29	.22	.12	1.31	.22	.11	1.31	.22	.10	1.27	.20	.13	1.28	.20	.12
College	1.25	.21	.17	1.26	.21	.17	1.26	.20	.16	1.26	.20	.15	1.26	.20	.16	1.26	.20	.16
Associate or higher	1.16	.17	.29	1.17	.17	.29	1.17	.17	.25	1.18	.16	.25	1.16	.16	.28	1.16	.16	.28
Unknown	1.23	.23	.27	1.23	.23	.26	1.21	.22	.31	1.21	.22	.29	1.18	.20	.34	1.18	.21	.35
Employment																		
Unemployed (ref)																		
Working	.51	.02	<.01	.51	.02	<.01	.51	.02	<.01	.51	.02	<.01	.51	.02	<.01	.51	.02	<.01
Insurance																		
Private (ref)																		

Medicaid	1.46	.07	<.01	1.46	.07	<.01	1.49	.08	<.01	1.48	.08	<.01	1.48	.07	<.01	1.48	.07	<.01
Medicare	.79	.02	<.01	.79	.02	<.01	.80	.02	<.01	.80	.02	<.01	.79	.02	<.01	.79	.02	<.01
VA	1.20	.10	.03	1.20	.10	.03	1.23	.10	.01	1.22	.10	.01	1.29	.11	.005	1.28	.11	<.01
Other government	1.04	.07	.56	1.04	.07	.56	1.03	.07	.68	1.03	.07	.72	1.00	.06	.966	1.00	.06	.96
Other self	.99	.11	.92	.99	.12	.90	1.03	.12	.78	1.02	.12	.84	1.00	.12	.983	1.00	.11	.98

Supplementary table 5a: Multiple regression results of listing for alcohol-related liver disease as a function of per capita alcohol consumption for spirits, wine, and beer*

	OR	95% CI	*p*
Consumption			
Spirits	1.62	1.06, 2.48	.03
Wine	1.36	.94, 1.96	.10
Beer	1.39	.88, 2.18	.16

*Age, sex, race and Hispanic ethnicity, education, employment, insurance, and list year were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 5b: Multiple regression results of listing for alcohol-related liver disease as a function of excise and ad valorem taxes for spirits, wine, and beer*

	On-premise			Off-premise		
	OR	95% CI	*p*	OR	95% CI	*p*
Spirits						
Excise tax	.80	.66, .98	.03	.83	.70, .99	.04
Ad valorem tax	.94	.81, 1.08	.39	1.05	.87, 1.27	.61
Wine						
Excise tax	.41	.10, 1.72	.22	.45	.12, 1.62	.22
Ad valorem tax	.99	.85, 1.15	.89	1.07	.88, 1.31	.50
Beer						
Excise tax	.03	.00, 1.23	.06	.03	.00, 1.09	.06
Ad valorem tax	.99	.87, 1.13	.85	.96	.77, 1.20	.74

*Age, sex, race and Hispanic ethnicity, education, employment, insurance, and list year were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 5c: Multiple regression results of listing for alcohol-related liver disease as a function of per capita consumption and excise and ad valorem taxes for spirits, wine, and beer*

	On-premise			Off-premise		
	OR	95% CI	*p*	OR	95% CI	*p*
Spirits						
Alcohol consumption	1.65	1.04, 2.59	.03	1.65	1.04, 2.61	.03
Excise tax	.86	.73, 1.01	.07	.86	.74, 1.01	.07
Ad valorem tax	.99	.87, 1.14	.93	1.02	.88, 1.18	.77
Wine						
Alcohol consumption	1.46	.91, 2.35	.12	1.45	.95, 2.22	.08
Excise tax	.44	.12, 1.67	.23	.45	.14, 1.45	.18
Ad valorem tax	1.05	.88, 1.24	.60	1.12	.93, 1.35	.24
Beer						

Alcohol consumption	1.40	.86, 2.28	.17	1.36	.86, 2.17	.19
Excise tax	.02	.01, .94	.05	.03	.00, 1.00	.05
Ad valorem tax	.95	.81, 1.11	.50	.99	.80, 1.23	.96

*Age, sex, race and Hispanic ethnicity, education, employment, insurance**,** and list year were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 6a: Multiple regression results of listing for alcohol-related liver disease as a function of per capita alcohol consumption for spirits, wine, and beer with Medicaid population removed*

	OR	95% CI	*p*
Consumption			
Spirits	1.63	1.14, 2.32	.01
Wine	1.51	1.07, 2.14	.02
Beer	1.22	.81, 1.83	.34

*Age, sex, race and Hispanic ethnicity, education, and employment were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 6b: Multiple regression results of listing for alcohol-related liver disease as a function of excise and ad valorem taxes for spirits, wine, and beer with Medicaid population removed*

	On-premise			Off-premise		
	OR	95% CI	*p*	OR	95% CI	*p*
Spirits						
Excise tax	.80	67, .95	.01	.83	.71, .97	.02
Ad valorem tax	.94	.82, 1.09	.42	1.07	.88, 1.31	.49
Wine						
Excise tax	.34	.08, 1.52	.16	.38	.10, 1.46	.16
Ad valorem tax	.99	.86, 1.15	.91	1.09	.88, 1.35	.43
Beer						
Excise tax	.05	.00, 1.58	.09	.04	.00, 1.43	.08
Ad valorem tax	.99	.87, 1.13	.91	.98	.77, 1.24	.84

*Age, sex, race and Hispanic ethnicity, education, and employment were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 6c: Multiple regression results of listing for alcohol-related liver disease as a function of per capita consumption and excise and ad valorem taxes for spirits, wine, and beer with Medicaid population removed*

	On-premise			Off-premise		
	OR	95% CI	*p*	OR	95% CI	*p*
Spirits						
Alcohol consumption	1.64	1.12, 2.40	.01	1.63	1.11, 2.41	.01
Excise tax	.86	.73, 1.01	.06	.86	.74, 1.00	.05
Ad valorem tax	1.00	.87, 1.15	.96	1.04	.89, 1.21	.63
Wine						
Alcohol consumption	1.67	1.08, 2.57	.02	1.64	1.10, 2.42	.01
Excise tax	.37	.10, 1.36	.14	.37	.12, 1.18	.09
Ad valorem tax	1.07	.91, 1.25	.43	1.15	.95, 1.39	.15

Beer							
	Alcohol consumption	1.20	.78, 1.85	.41	1.18	.78, 1.78	.43
	Excise tax	.04	.00, 1.48	.08	.04	.00, 1.44	.08
	Ad valorem tax	.97	.83, 1.13	.70	.99	.78, 1.27	.96

*Age, sex, race and Hispanic ethnicity, education, and employment were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 7a: Multiple regression results of listing for alcohol-related liver disease as a function of per capita alcohol consumption for spirits, wine, and beer *

	OR	95% CI	*p*
Consumption			
Spirits	1.50	.98, 2.31	.06
Wine	.99	.65, 1.51	.98
Beer	1.63	1.07, 2.47	.02

*Age, sex, race and Hispanic ethnicity, education, employment, insurance, and household income were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 7b: Multiple regression results of listing for alcohol-related liver disease as a function of excise and ad valorem taxes for spirits, wine, and beer*

	On-premise			Off-premise		
	OR	95% CI	*p*	OR	95% CI	*p*
Spirits						
Excise tax	.82	.68, .98	.03	.82	.69, .98	.03
Ad valorem tax	1.00	.89, 1.13	.98	1.06	.94, 1.20	.37
Wine						
Excise tax	.76	.16, 3.70	.74	.74	.18, 3.05	.67
Ad valorem tax	1.05	.92, 1.19	.50	1.09	.96, 1.23	.20
Beer						
Excise tax	.23	.01, 10.23	.45	.20	.01, 7.30	.38
Ad valorem tax	1.03	.92, 1.16	.59	1.00	.85, 1.17	.98

*Age, sex, race and Hispanic ethnicity, education, employment, insurance, and household income were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 7c: Multiple regression results of listing for alcohol-related liver disease as a function of per capita consumption and excise and ad valorem taxes for spirits, wine, and beer*

	On-premise			Off-premise		
	OR	95% CI	*p*	OR	95% CI	*p*
Spirits						
Alcohol consumption	1.56	1.04, 2.44	.05	1.53	.96, 2.645	.07
Excise tax	.86	.74, 1.00	.05	.85	.73, 0.99	.04
Ad valorem tax	1.03	.92, 1.15	.57	1.03	.92, 1.15	.63
Wine						
Alcohol consumption	1.00	.58, 1.71	1.00	1.00	.58, 1.69	.99
Excise tax	.76	.16, 3.61	.73	.74	.18, 3.06	.68
Ad valorem tax	1.05	.90, 1.21	.55	1.09	.94, 1.25	.26

Beer							
	Alcohol consumption	1.59	1.02, 2.47	.04	1.61	1.06, 2.45	.03
	Excise tax	.34	.01, 8.43	.51	.41	.02, 8.48	.56
	Ad valorem tax	.99	.88, 1.12	.90	1.06	.93, 1.20	.39

*Age, sex, race and Hispanic ethnicity, education, employment, insurance**,** and household income were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 8a: Multiple regression results of listing for Hepatitis B disease as a function of per capita alcohol consumption for spirits, wine, and beer*

	OR	95% CI	*p*
Consumption			
Spirits	.94	,57, 1.57	.83
Wine	1.71	.94, 3.10	.08
Beer	.89	.55, 1.43	.62

*Age, sex, race, education, employment, and insurance were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 8b: Multiple regression results of listing for Hepatitis B liver disease as a function of excise and ad valorem taxes for spirits, wine, and beer*

	On-premise			Off-premise		
	OR	95% CI	*p*	OR	95% CI	*p*
Spirits						
Excise tax	.82	.57, 1.18	.28	.86	.62, 1.18	.35
Ad valorem tax	.89	.73, 1.10	.28	1.06	.86, 1.32	.56
Wine						
Excise tax	.49	.03, 8.53	.62	.60	.04, 10.16	.73
Ad valorem tax	.92	.74, 1.14	.45	1.08	.86, 1.37	.51
Beer						
Excise tax	1.14	.77, 1.70	.51	1.18	.80, 1.73	.40
Ad valorem tax	.99	.79, 1.23	.90	1.14	.92, 1.42	.23

*Age, sex, race, education, employment, and insurance were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 8c: Multiple regression results of listing for Hepatitis B liver disease as a function of per capita consumption and excise and ad valorem taxes for spirits, wine, and beer*

	On-premise			Off-premise		
	OR	95% CI	*p*	OR	95% CI	*p*
Spirits						
Alcohol consumption	.87	.46, 1.66	.67	.89	.51, 1.54	.67
Excise tax	.81	.55, 1.18	.27	.85	.61, 1.19	.35
Ad valorem tax	.88	.70, 1.12	.31	1.08	.88, 1.32	.45
Wine						
Alcohol consumption	1.67	.92, 3.05	.09	1.75	1.00, 3.05	.05
Excise tax	.54	.05, 6.35	.63	.62	.06, 6.63	.69
Ad valorem tax	.99	.82, 1.20	.91	1.13	.95, 1.36	.17
Beer						

Alcohol consumption	.85	.52, 1.38	.50	.87	.56, 1.39	.56
Excise tax	1.16	.78, 1.73	.45	1.19	.81, 1.74	.37
Ad valorem tax	1.01	.81, 1.25	.95	1.13	.90, 1.43	.30

*Age, sex, race, education, employment, and insurance were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 9a: Multiple regression results of listing for alcohol-related hepatitis disease as a function of per capita alcohol consumption for spirits, wine, and beer*

	OR	95% CI	*p*
Consumption			
Spirits	2.22	.65, 7.52	.20
Wine	1.08	.31, 3.76	.90
Beer	.94	.31, 2.88	.91

*Age, sex, race, education, employment, and insurance were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 9b: Multiple regression results of listing for alcohol-related hepatitis liver disease as a function of excise and ad valorem taxes for spirits, wine, and beer*

	On-premise			Off-premise		
	OR	95% CI	*p*	OR	95% CI	*p*
Spirits						
Excise tax	.93	.86, .99	.03	.92	.86, .99	.02
Ad valorem tax	1.04	.73, 1.49	.83	.96	.65, 1.43	.84
Wine						
Excise tax	1.26	.80, 2.00	.32	1.21	.77, 1.91	.41
Ad valorem tax	1.30	.90, 1.87	.16	1.16	.71, 1.87	.55
Beer						
Excise tax	.60	.17, 2.08	.42	.57	.17, 1.94	.37
Ad valorem tax	1.19	.88, 1.61	.26	1.07	.72, 1.59	.73

*Age, sex, race, education, employment, and insurance were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 9c: Multiple regression results of listing for alcohol-related hepatitis liver disease as a function of per capita consumption and excise and ad valorem taxes for spirits, wine, and beer*

	On-premise			Off-premise		
	OR	95% CI	*p*	OR	95% CI	*p*
Spirits						
Alcohol consumption	2.70	.87, 8.37	.09	2.54	.80, 8.04	.11
Excise tax	.94	.88, 1.01	.07	.93	.87, .99	.03
Ad valorem tax	1.17	.78, 1.74	.44	.90	.54, 1.51	.70
Wine						
Alcohol consumption	2.72	.65, 11.27	.17	1.87	.51, 6.91	.35
Excise tax	1.28	.85, 1.91	.24	1.21	.79, 1.85	.39
Ad valorem tax	1.49	.95, 2.34	.08	1.24	.72, 2.13	.43
Beer						

Alcohol consumption	.90	.26, 3.13	.87	1.01	.34, 2.99	.99
Excise tax	.61	.17, 2.17	.44	.57	.17, 1.93	.37
Ad valorem tax	1.20	.82, 1.78	.35	1.07	.72, 1.60	.73

*Age, sex, race, education, employment, and insurance were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 10a: Multiple regression results of primary or secondary listing for alcohol-related liver disease as a function of per capita alcohol consumption for spirits, wine, and beer*

	OR	95% CI	*p*
Consumption			
Spirits	1.64	1.08, 2.50	.02
Wine	1.37	.85, 2.21	.20
Beer	1.48	.97, 2.26	.07

*Age, sex, race, education, employment, and insurance were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 10b: Multiple regression results of primary or secondary listing for alcohol-related liver disease as a function of excise and ad valorem taxes for spirits, wine, and beer*

	On-premise			Off-premise		
	OR	95% CI	*p*	OR	95% CI	*p*
Spirits						
Excise tax	.81	.66, .99	.04	.82	.68, .98	.03
Ad valorem tax	1.00	.84, 1.17	.96	1.07	.90, 1.27	.43
Wine						
Excise tax	.44	.11, 1.83	.26	.42	.12, 1.50	.18
Ad valorem tax	1.06	.90, 1.25	.47	1.08	.91, 1.29	.39
Beer						
Excise tax	.03	.00, 2.30	.12	.02	.00, 1.53	.08
Ad valorem tax	1.06	.91, 1.23	.45	.95	.75, 1.20	.65

*Age, sex, race, education, employment, and insurance were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

Supplementary table 10c: Multiple regression results of primary or secondary listing for alcohol-related liver disease as a function of per capita consumption and excise and ad valorem taxes for spirits, wine, and beer*

	On-premise			Off-premise		
	OR	95% CI	*p*	OR	95% CI	*p*
Spirits						
Alcohol consumption	1.71	1.12, 2.62	.01	1.66	1.04, 2.65	.03
Excise tax	.87	.74, 1.02	.09	.85	.70, 1.03	.09
Ad valorem tax	1.05	.89, 1.24	.54	1.03	.90, 1.18	.64
Wine						
Alcohol consumption	1.56	.91, 2.67	.11	1.42	.81, 2.47	.22
Excise tax	.47	.12, 1.85	.28	.42	.12, 1.46	.17
Ad valorem tax	1.13	.95, 1.34	.17	1.12	.95, 1.33	.19
Beer						

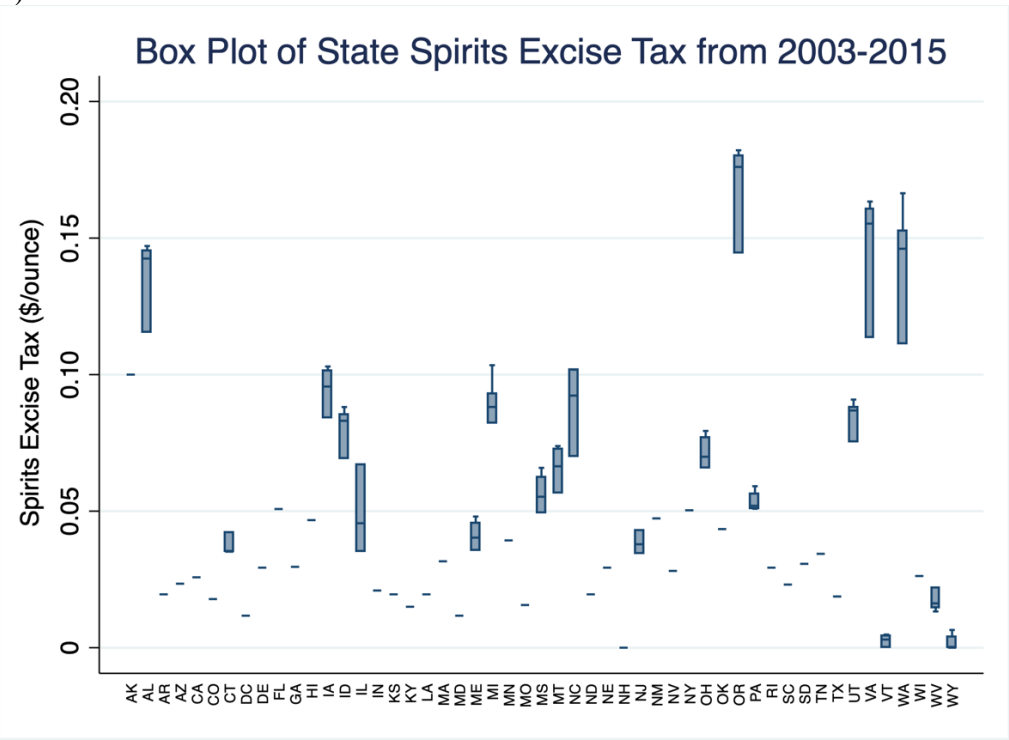
Alcohol consumption	1.44	.91, 2.29	.12	1.45	.93, 2.26	.10
Excise tax	.03	.00, 1.81	.09	.02	.00, 1.51	.08
Ad valorem tax	1.02	.88, 1.18	.84	.99	.77, 1.26	.90

*Age, sex, race, education, employment, and insurance were controlled for in multiple regression analysis. Clustering was conducted at the state-level.

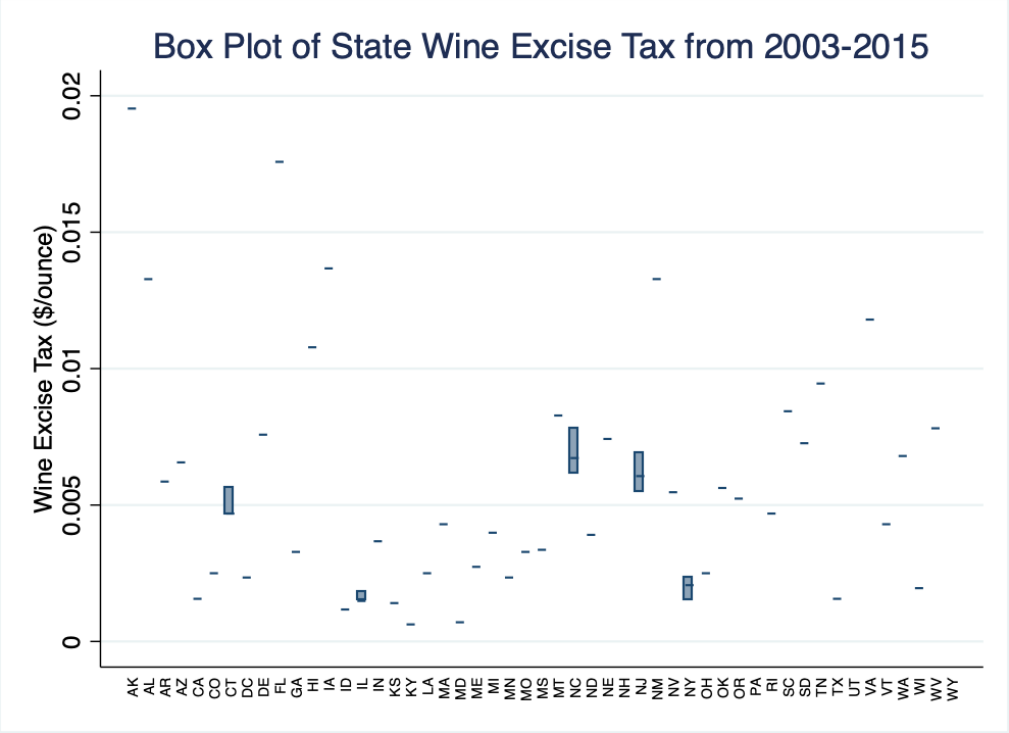
Supplementary Figures

Supplementary Figure 1a-c: Box plots showing the changes in spirits (a), wine (b), and beer (c) excise taxes by state from 2003-2015.

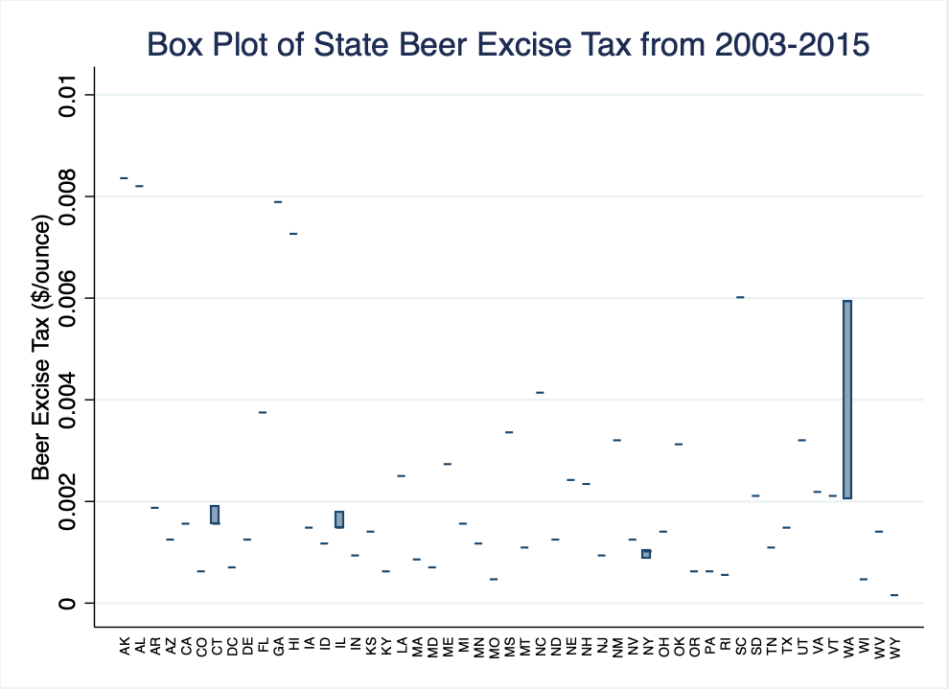
a)



b)


Box Plot of State Wine Excise Tax from 2003-2015
Wine Excise Tax ($/ounce)
0
0.005
0.01
0.015
0.02
AK AL AR AZ CA CO CT DC DE FL GA HI IA ID IL IN KS KY LA MA MD ME MI MN MO MS MT NC ND NE NH NJ NM NV NY OH OK OR PA RI SC SD TN TX UT VA VT WA WI WV WY

c)


Box Plot of State Beer Excise Tax from 2003-2015
Beer Excise Tax ($/ounce)
0
0.002
0.004
0.006
0.008
0.01
AK AL AR AZ CA CO CT DC DE FL GA HI IA ID IL IN KS KY LA MA MD ME MI MN MO MS MT NC ND NE NH NJ NM NV NY OH OK OR PA RI SC SD TN TX UT VA VT WA WI WV WY