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New estimates of the mean ethanol content of beer, wine, and spirits sold in the U.S. show a greater increase in per capita alcohol consumption than previous estimates

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ABSTRACT

Background: Recent increases in alcohol-related morbidity and mortality have not occurred alongside notable increases in per capita alcohol consumption (PCC). This discrepancy may be partially due to U.S. PCC estimates not including annual estimates of the % alcohol by volume (%ABV) of beer, wine, and spirits, but rather relying on time-invariant %ABV values.

Methods: Building on a prior study covering 1950-2002, estimates of the annual mean %ABV of beer, wine, and spirits sold in the U.S. were calculated using the %ABV of major brands and sales of each beverage type for each state and nationally for the period 2003 to 2016. We applied these estimates to the calculation of annual beverage-specific and total PCC, and made descriptive comparisons between our PCC estimates and those estimates using invariant %ABV values.

Results: For all beverage types, our mean %ABV estimates increased nationally and for all but five states. The PCC estimates from wine and spirits utilizing variable %ABV values were lower than estimates using invariant %ABV, and consumption from beer was higher. Our total PCC estimates were also lower than %ABV-invariant estimates, however, the percent change for %ABV-invariant estimates was 5.8% compared to a 7.9% change in our %ABV-variant estimates over the 2003-2016 period.

Conclusions: Given the application of PCC estimates to understand changes in alcohol-related morbidity and mortality, the inclusion of annual estimates of the

%ABV of alcoholic beverages sold in the U.S. is necessary to ensure the precision of PCC measures such that the conclusions drawn from these applications are accurate and valid.

Key words: Per capita consumption, trends, alcohol content

INTRODUCTION

Since the late 1990's, there have been dramatic increases in alcohol-related problems in the United States. Between 1999 and 2016 annual deaths from liver cirrhosis increased by 65% and doubled for liver cancer (Tapper and Parikh, 2018). Relatedly, from 2006 to 2016 the death rate from alcoholic liver disease increased by over 40% from 4.1 per 100,000 to 5.9 per 100,000 (CDC, 2017). An increase of nearly 62% in alcohol-related emergency department (ED) visits was also found between 2006 and 2014 from 3,080,214 to 4,976,136 visits per year, with the increase occurring predominantly among people aged 45 and older (White et al., 2018). Further, an analysis of data from two waves of the National Epidemiologic Survey of Alcohol and Related Conditions (NESARC) showed a nearly 50% increase in the prevalence of past year alcohol use disorder (AUD) from 2002 to 2013 among adults aged 18 and above (Grant et al., 2017).

Surprisingly, these increases in alcohol-related morbidity and mortality did not occur alongside notable increases in per capita alcohol consumption (PCC) estimates. These estimates, based on beverage sales data collected by the Alcohol Epidemiologic Data System (AEDS), increased by approximately 6% over the 2002-2013 time period (Haughwout, 2018). This represents an increase of approximately

28 drinks per person per year (where a drink is 0.6oz of ethanol, which is equal to 12oz of 5% ABV beer, 5oz of 12% wine, and 1.5oz of 40% spirits) (NIAAA, 2018). This increase seems insufficient to explain the observed increases in alcohol-related morbidity and mortality, as we would expect a notable increase given that the heaviest drinkers consume the vast majority of alcohol (Kerr and Greenfield, 2007). Indeed, the increase in the rate of alcohol-related ED visits between 2006 and 2014 was considered unrelated to the concomitant 1.7% increase in PCC (White et al., 2018). A possible explanation for the discrepancy between alcohol-related problems and PCC may lie in how PCC estimates are calculated.

Per capita alcohol consumption is typically constructed as an aggregate measure using national and state population estimates from the U.S. Census Bureau and alcohol sales data (Haughwout, 2018). The state-level alcohol sales figures are from either state-provided taxable withdrawals from bonded warehouses or industry sources for states that fail to provide data. Alcohol sales-based consumption estimates are considered more complete and objective than survey data on alcohol use, which is subject to substantial under-reporting (Kerr and Greenfield, 2007, Greenfield and Kerr, 2008). This consideration is also due to the widespread availability of alcohol tax information and the low level of unrecorded alcohol use in the U.S. (WHO, 2014). However, the precision of typical PCC estimates is challenged by the fact that they use invariant estimates of the mean percentage of alcohol by volume (%ABV), i.e. they do not use annual estimates of the alcohol content of the beer, wine, and spirits sold in each state to convert beverage volume into ethanol. The conversion factors used in the typical PCC estimate approach are based on estimates of %ABV for each beverage type and have not been updated since the 1970s. These values are 4.5%, 12.9%, and 41% for beer, wine, and spirits, respectively. Further complicating the issue is that each beverage type is comprised of several subtypes (e.g. – beer is comprised of light beer, craft beer, and imported beer, among others) each with different %ABVs. Thus, actual PCC is also influenced by changes over time and place in beverage subtype preferences. Failing to acknowledge these changes in %ABVs and beverage preferences risks underestimating important changes in actual PCC that could potentially explain observed changes in alcohol-related morbidities and mortality. Additionally, PCC estimates are key to the estimation of the alcohol-attributable morbidity and mortality used to assess the global burden of disease due to alcohol (Sherk, 2017). Indeed, PCC estimates are the marker against which the estimation of an exposure distribution of alcohol are based (Kehoe et al., 2012).

Our previous work has demonstrated meaningful changes in the alcohol content of beer, wine, and spirits during the last half of the 20th century. The mean %ABV of beer and spirits sold in the U.S. have each declined between 1950 and 2002 (Kerr et al., 2006a). The %ABV of wine declined between 1950 and the mid-1980s to 10.5%, whereafter it began and continued to increase to 11.5%. Beyond 2002 there is reason to believe there have been further changes in the %ABVs of beverage types with the emergence of high %ABV craft beer (Beverage Information Group, 2011) and a likely continued increase in the %ABV of wine (Frazer, 2014).

The aim of this paper is to extend our previous work estimating the mean alcohol concentration of the beer, wine, and spirits sold in the U.S. and PCC to the period 2003 to 2016. We present the variation in %ABV over this time period for each beverage type and examine this variation in light of changes in beverage subtype preferences and mean %ABV. We compare PCC estimates based on our

ABV-variant methods to estimates from ABV-invariant methods nationally and for each state.

METHODS

Overview. The general methodology we employed to obtain PCC estimates that account for variations in the mean %ABV for each beverage type is as follows. First, we estimated a sales-weighted mean %ABV for each industry-defined beverage subtype (e.g., – light beer, dessert wine, vodka) based on leading brands sold for each year. We then applied these mean beverage subtype %ABV values to the calculation of each state's and the nation's mean %ABV for each beverage type for each year using the market shares of each beverage subtype sold in each state and nationally. Finally, we used these annual mean %ABV estimates for each beverage type in the calculation of beverage-specific and total PCC estimates for each state and nationally for each year from 2003 to 2016. These methods are based on those employed in previous publications for beer (Kerr and Greenfield, 2003, Kerr, 2008, Kerr et al., 2004), wine (Kerr et al., 2006b, Kerr et al., 2006a), and spirits (Kerr et al., 2006a).

Data sources for beer. We used the Beer Handbooks to obtain data on which brands were the leading brands, the volume sold of each leading brand, and state and national annual market shares of each beer subtype (Beverage Information Group, 2017a).

As of 2002, the Beer Handbooks no longer included %ABV values (Adams Beverage Group, 2002), and The Siebel Institute of Technology did not produce new editions of the reports we used previously (Seibel Institute of Technology, 1994, Seibel Institute of Technology, 1995). Therefore, we obtained brewer-reported

%ABV values from brewer websites, or the Liquor Control Board of Ontario's website, or, in the case that %ABVs could not be identified from these sources, we carried forward the 2002 %ABV value. Between 2000 and 2010 the Beer Handbooks grouped the sale of beer into the following 7 categories: Super premium, micro/specialty, flavored malt beverages; premium beer; light beer; popular beer; malt beer; ice beer, and imported beer (Adams Beverage Group, 2010). In 2011 the "super premium, micro/specialty, flavored malt beverages" category was divided into the categories "craft beer" and "flavored malt beverages", and "super premium beer" was included in the "premium beer" category (Beverage Information Group, 2011). Thus, between 2011 and 2016 there were 8 industry-defined categories of beer. We calculated sales-weighted mean %ABV values (described below) for each beer subtype according to these industry-defined categories as they changed over time.

Data sources for wine. For wine, we identified data on top-selling varietals from the leading wine brands from the National Alcoholic Beverage Control Association (NABCA) database. The NABCA database includes sales of all wine brands by state alcohol monopolies by state and year. We chose leading brands based on sales in Pennsylvania because only 5 states control wine sales, and of those Pennsylvania is the largest (Kerr et al., 2016). We did not use national wine sales data because such data were available only for general brands (e.g. – Franzia Winetaps, Sutter Home) which included multiple varietals (e.g. – chardonnay, merlot) with differing %ABVs. We obtained the annual market shares of each wine subtype in each state and nationally from the Wine Handbooks (Beverage Information Group, 2017c). These industry-defined wine subtypes are table wine, wine coolers, champagne and sparkling wine, dessert and fortified wine, and vermouth/aperitif. Pennsylvania as a state alcohol monopoly follows NABCA subtypes for wine that differs from those used in the Wine Handbooks. Because annual market shares are based on the Wine Handbook’s industry-defined wine subtype categories, we first matched the sales and %ABV data for each brand varietal and then grouped the matched brands according to the Wine Handbook’s categories.

Data on the %ABV of specific wine brand and varietal were obtained from Washington State Liquor Control Board (WSLB) Price Lists for the years 2003 – 2012. As WSLB did not produce these price lists after the privatization of alcohol sales in 2012, we used the Liquor Control Board of Ontario’s website to identify %ABV. In the case that a specific brand varietal for a specific year could not be identified in either of these sources, we used the winery-reported value as reported on their websites. As previously described (Kerr et al., 2006b), we did this for each brand varietal accounting for the top 80% of wine sales in Pennsylvania for each wine subtype. There were many thousands of brand varietals sold comprising the largest category “table wine”, and an increasing number of brands each year. Further, this methodology of identifying %ABV for each varietal has been critiqued as too labor-intensive (Haughwout, 2018). To address the labor-intensity of this process, in this update of %ABV estimates and PCC we matched sales and %ABV for the top 50% of table wine sales in Pennsylvania, and calculated a mean %ABV for 30% of the total sales of table wines. We calculated a mean %ABV for the most commonly sold varietals, which were chardonnay, cabernet sauvignon, merlot, and zinfandel, by obtaining the %ABV for all the wines listed in these varietal categories, excluding those already included in the top 50%. We applied this mean %ABV to 30% of the total sales volume thus increasing our mean %ABV estimate to include 80% of the total. This was feasible for each year from 2003 to 2011 because the Washington Price lists were available and included %ABV values for each brand varietal in each top-selling varietal category. For the years from 2012 to 2016 we carried forward the 2011 %ABV value representing the mean of the most commonly sold varietals and applied it to each year's 30% value of total sales volume.

Data sources for spirits. We used the Liquor Handbooks to obtain data on the leading brands, the volume sold of each, and state and national annual market shares of each spirits subtype (Beverage Information Group, 2017b). Spirits subtype categories were straight whiskey, blended whiskey, Canadian whiskey, Scotch whiskey, Irish whiskey, gin, vodka, rum, tequila, brandy & cognac, cordials & liqueurs, and prepared cocktails. We obtained %ABV values for each brand within each spirits subtype from the WSLB Price Lists for the years 2003 – 2012 and from the NABCA database for the years 2013-2016. If the %ABV could not be identified from these sources we used values from the distillery's website.

Other data sources. We used sales figure data for 2003-2016 from the Alcohol Epidemiologic Data System (AEDS) for the volume of each beverage type sold for each state and nationally for each year (Nephew et al., 2004, Haughwout, 2018). These figures are based on tax receipts and industry sources. We obtained estimates of the United States population aged 15 and older for each state and nationally from 2003 to 2016 from the U.S. Census Bureau (U.S. Census Bureau, 2011, U.S. Census Bureau, 2017). The AEDS figures presented here based on the ABV-invariant method are not the same as those in the AEDS Surveillance reports because here they are referenced to the population aged 15 and older, while AEDS reports used figures for the population aged 14 and older.

Estimating sales-weighted mean % ABV. To estimate the sales-weighted mean %ABV for each beverage subtype for each year we 1) multiplied the %ABV for each leading brand by the volume sold (2.25-gallon cases for beer subtypes and 9-liter cases for wine and spirits subtypes), 2) took the sum of these product values and 3) divided this sum by the sum of the volume sold. To estimate the mean %ABV for each beverage type we multiplied the annual market share of each beverage subtype by the sales-weighted mean %ABV of that subtype and summed across all beverage subtypes for each state for each year, and nationally for each year.

Estimating per capita alcohol consumption. Nationally and for each state we calculated PCC estimates for each beverage type by multiplying the mean %ABV by the volume (in gallons) of each beverage type sold and dividing by the population aged 15 and above. The total PCC is the sum of per capita consumption of each beverage type. To be consistent with international standards, we present PCC estimates in liters.

We describe our %ABV estimates for beer, wine, and spirits, their trends between 2003 and 2016, and make comparisons to the static %ABV values used in the AEDS PCC calculations. To explain the trends in %ABV estimates for each beer, wine, and spirits, we describe the mean %ABV and market shares for beverage subtypes. We describe our beverage-specific and total PCC estimates and trends, and make trend comparisons to estimates from the AEDS ABV-invariant methods. We present national estimates as described above followed by a brief overview of state estimates.

RESULTS

National %ABV estimates for beer, wine, and spirits. Our estimates of the mean %ABV of beer, wine, and spirits sold in the United States between 2003 and 2016 are presented in Figure 1. Overall, the means for all beverage types increased over the 2003-2016 period from 4.65% to 4.74 %ABV, 11.6% to 12.3 %ABV, and 36.9% to 38.3 %ABV for beer, wine, and spirits, respectively.

For beer, the overall trend in mean %ABV was a decline between 2003 and 2005, a small increase in 2006 followed by a steady decline until 2010, after which there was a notable increase until 2015 and a slight decline to 2016. Our estimates were consistently higher than the time-invariant 4.5 %ABV value used for every year in AEDS, with the largest difference of 0.25 percentage points in 2015.

For wine, the overall trend in average %ABV was a stable value between 2003 and 2007, then a sharp increase until 2010 after which it declined slightly and remained relatively stable until 2016. Our estimates were lower than the time-invariant 12.9 %ABV value for every year in AEDS but the difference decreased over time as our estimates increased.

For spirits, the overall trend in mean %ABV showed a steady increase between 2003 and 2014, with a slight dip in 2015 and an increase in 2016. Our estimates were consistently lower than the static AEDS estimates, although differences decreased over the time period as our estimates increased.

National mean %ABVs and market shares for beverage subtypes. The changes we observed in our national estimates of mean %ABV of each beverage type were influenced by changes in the sales-weighted mean %ABVs of beverage subtypes and changes in beverage subtype market shares over time, that is, changes in beverage subtype preferences. The %ABVs and market shares are presented for selected years for each beverage type in Table 1.

The initial decrease in the mean %ABV of beer between 2003 and 2005 (see Figure 1) was driven by declines in market shares and not %ABV as beer subtypes' mean %ABV changed by no more than 0.03 over this time period. Premium beer and popular beer had the second and fourth largest market shares in 2003, respectively, and each lost about 12% of their market shares by 2005. On the other hand, the increase in the national mean %ABV of beer between 2005 and 2006 was the result of an increase in the mean %ABV of malt beverages, which increased from 6.14% to 6.68 %ABV. This increase was driven by the brand Steel Reserve, with a %ABV of 8.1%, as the top-selling brand in the malt beer category from 2006 onwards. Also between 2005 and 2006 the market share of malt beer increased by about 29%, although it still only comprised less than 3% of the market share in 2006. The decline in the national mean %ABV of beer between 2006 and 2010 was explained by the continued decline in market shares of premium beer, which lost 20% of its market shares over this period. The marked increase in the national mean %ABV of beer from 2010 to 2016 was driven by the increase in mean %ABV and market shares of flavored malt beverages (FMBs) and of craft beer. The mean %ABV of FMBs increased from 5.9% to 6.5%, and of craft beer from 4.9% to 5.3% between 2011 and 2016. Over the same period FMBs increased its market share by approximately 56%, while craft beer increased by approximately 85%. It is also important to note that light beer, which had a stable %ABV over time of about 4.3%, showed a steady decline in market shares from a high of 52.9% in 2010 to 44.5% in 2016.

The increase in the mean %ABV of wine between 2007 and 2010 was driven by increases in the sales-weighted mean %ABV of table wine. Table wines increased from 11.7 in 2007 to 12.4 %ABV in 2010 when the %ABV peaked and changed little thereafter. Table wines comprised the vast majority of wine sales nationally with a market share consistently around 90%. This market share changed little over the entire 2003-2016 period from 90.2% to 90.7%, and was highest in 2010 at 91.8%. The slight decline in the mean %ABV of wine between 2010 and 2011 was attributable to the decline in the mean %ABV of dessert and fortified wine from 15.0% to 14.1%, which also lost market shares by approximately 16% between 2010 and 2011, although comprised only 3% of the market in 2010.

Spirits showed a steady increase in mean %ABV over the 2003 to 2016 period, reflecting a gradual increase in the market shares of higher %ABV spirits and a gradual decrease in lower %ABV spirits. Vodka, with a mean 40% ABV throughout the study period, showed the largest rise in market shares from 26.2% in 2003 to 33.6% in 2016. Similarly, market shares of tequila, also with a mean 40% ABV, increased market shares from 4.8% to 7.2%. Straight whiskey also increased its market shares from 8.4% to 9.5% between 2003 and 2016, and had a slight increase in mean %ABV from 41.1% to 41.9%. There were limited changes in the mean %ABV of spirits subtypes, with the exception of cordials & liqueurs and prepared cocktails. Cordials & liqueurs showed an increase of mean %ABV from 23.7% to 28.4%, and prepared cocktails from 9.7% to 11.9%.

National beverage-specific and total per capita alcohol consumption estimates. The new national variant %ABV-based PCC estimates for beer, wine, and spirits, and for total consumption, with comparisons to AEDS estimates are presented in Figure 2. Overall, our new estimates showed that consumption of pure alcohol from beer was somewhat higher for every year and that consumption of alcohol from wine, spirits, and total PCC was lower in every year compared to AEDS estimates.

Our PCC estimates from beer decreased from 4.8 to 4.4 liters per capita between 2003 and 2016 and showed a similar trend over time compared to AEDS estimates. However, the percent difference between the AEDS and our estimates increased between 2011 and 2016 from 3.2% to 5.1% showing that the trends diverge slightly.

Our PCC estimates from wine increased from 1.2 to 1.6 liters per capita between 2003 and 2016. The trend is similar to AEDS estimates, although there is a notable convergence between our estimates and the AEDS estimates, where the percent difference decreased from 9.7% in 2003 to 5.0% in 2016.

Our estimates of PCC from spirits increased between 2003 and 2016 from 2.31 to 2.98 liters per capita and followed a very similar trend to the AEDS estimates, remaining mostly parallel over the study period. A slight convergence was observed as the percent difference between our estimate and the AEDS estimate was 10.3% in 2003, 7.9% in 2015 and 6.8% in 2016.

Our total PCC estimates followed a similar pattern over the 2003 to 2016 period to that of the AEDS estimates (see Figure 2). However, there are important differences. Overall, our total PCC estimates were lower than the AEDS estimates. Further, the trend for our estimate converged with the AEDS estimate trend. The difference between our estimates declined from 0.24 liters of alcohol per person in 2003 to a difference of just 0.08 liters in 2016. Importantly, the percent change between 2003 and 2016 for the AEDS estimates was 5.8% compared to a 7.9%

change in our estimates over the same period. This 7.9% change represents 0.66 liters, which is a mean of approximately 37 drinks per person per year. In contrast, a 5.8% change represents 0.48 liters, which is a mean of approximately 27 drinks per person per year.

State %ABV estimates for beer, wine, and spirits. The estimates of the mean %ABV of beer, wine, and spirits for each state and the District of Columbia (D.C.) for selected years are presented in Table 3. The mean %ABV of each beverage type are seen to vary by state in each year, reflecting the variation in preferences and mean %ABV for each beverage subtype across states and time.

All states and the District of Columbia (DC) showed an increase in the mean %ABV of beer between 2003 and 2016, and most states followed the national trend. The states with the least amount of change over the 2003-2016 period were North Dakota, Virginia, and Iowa with *percent* increases of 1.2%, 1.1%, and 0.9%, respectively, while New Mexico, Montana, and Maine experienced the greatest *percent* increases of 4.9%, 4.4%, and 4.3%, respectively.

For wine, all states showed an increase in mean %ABV and followed the national trend. The states with the greatest increases between 2003-2016 were Idaho, Virginia, and Tennessee with increases of 6.8%, 6.8%, and 6.7%, respectively. The states with the lowest percent change were Illinois, North Carolina, and Mississippi with increases of 3.1%, 3.0%, and 2.9%, respectively.

For spirits, 45 states and the District of Columbia showed increases in the mean %ABV of spirits, and of these the vast majority followed the national trend. Ohio, Rhode Island, and Nebraska had the largest percent increases at 10.5%, 7.9%, and 6.6%, respectively, while West Virginia, Mississippi, and Alabama had the largest decreases in %ABV for spirits of 0.4%, 0.5%, and 1.8%, respectively.

State mean %ABVs and market shares for beverage subtypes. The change in the mean %ABV of beer, wine, and spirits was driven by changes in beverage subtype mean %ABVs and preferences, and these %ABVs and preferences varied by state. To describe these state-level beverage subtype %ABV and preference changes in relation to state-level changes in mean beverage-specific %ABV, we present data for the states with the largest change in mean %ABV for each beverage type.

The increase in %ABV of beer for New Mexico, which had the largest *percent* increase of 4.9%, is attributable to a decline in the market shares of beer with relatively low mean %ABV and an increase of relatively higher mean %ABV beer subtypes. Between 2006 and 2016 the market shares of light beer declined from 51.5% to 37.6%. The market shares of the super premium, micro/specialty, and FMBs subtype category increased from 6.8% in 2006 to 11.9% in 2010, and between 2011 and 2016 the market shares of craft beer increased from 8.2% to 14.9%.

Similar to the national trends in the mean %ABV of wine, state-level trends were driven by the increase in the mean %ABV and the market shares of table wine. Idaho, which had the largest percent change in mean %ABV of wine of 6.8%, had the largest market share of table wine for most years between 2003 and 2016, where market shares of table wine were 97.3% in 2003 and 97.4% in 2016.

Comparable to national trends in the mean %ABV of spirits, state level trends were driven by declines in the market shares of low %ABV spirit subtypes and increases in high %ABV spirit subtypes. Between 2003 and 2016, Ohio had the largest increase in mean spirits %ABV of 10.5%. Unlike the national trend, it showed a marked increase between 2012 and 2014 afterwhich it leveled off. The increase in %ABV between 2012 and 2014 was driven by a decline in the market shares of prepared cocktails from 9.3% in 2012 to 0.2% in 2014 and a concomitant increase in the market shares of cordials and liqueurs, straight whiskey, tequila, and brandy & cognac.

State beverage-specific and total per capita alcohol consumption estimates. The new beverage-specific %ABV-variant PCC estimates for selected years for each state are presented in Table 3. The estimates varied by state while trends for each beverage type were consistent across states. The total PCC estimates for each state with comparisons to AEDS estimates for 2003 and 2016 are presented in Table 4. The estimates varied by state in each year, representing the range in total PCC by state. Table 4 also shows the percent change in total PCC for each state for both our new estimates and the AEDS estimates. The ranking by percent change varies by the new and AEDS estimates. North Dakota has the largest percent change in total PCC according to both estimates, however, the new estimates rank Vermont second followed by Idaho while the AEDS estimate rank Idaho second followed by Vermont. The vast majority of states showed an increase in total PCC, although 2 more states, Nebraska and Illinois, showed a decline according to AEDS estimates than did according to our new estimates.

DISCUSSION

For all beverage types, our mean %ABV estimates increased nationally and for all but five states. These increases were driven by an increase in national and state preferences for beverages with a higher *and increasing* %ABV and a decrease in preferences for lower %ABV beverages. The estimates of PCC from wine and spirits utilizing variable %ABV conversion factors were lower than AEDS estimates, while consumption from beer was higher. While our total PCC estimates were also lower than AEDS estimates, the trends in PCC showed a more dramatic increase in pure alcohol volume than those using ABV-invariant methods.

Researchers have used PCC estimates to try to understand the observed increases in alcohol-related morbidity and mortality in the U.S. over the first part of the 21st century. For example, White et al noted an increase of 1.7% in PCC and concluded that it did not appear to be related to the 47% increase in the rate of alcohol-related ED visits from 2006 to 2014 (White et al, 2018). Using our ABV variant method, PCC between 2006 and 2014 increased by 3.6%, over double the increase using the ABV invariant method. This difference and the absolute increase using the ABV variant method may not alone explain the increase in the rate of alcohol-related ED visits. However, because the change in PCC was likely underestimated, it suggests PCC should not be dismissed and may be one of many factors driving the increase in alcohol-related emergency room visits. This example also highlights the importance of the rate of change in PCC trends, and is consistent with findings from an Australian study that similarly showed the value of including time-varying ABV values to ensure precision in PCC estimates so change over time can be accurately measured (Chikritzhs et al., 2010). It is important to note that cohort and lag effects may also be drivers of the disparity between changes in alcohol-related morbidity and mortality and changes in PCC. Cohort effects may be related in that previous generations may have been drinking at high levels that resulted in death from alcohol-related diseases so that their alcohol consumption would not be included in current PCC estimates (Trias-Llimós et al., 2017). Lag effects may contribute because the time from changes in PCC to the time to first effect for some alcohol-attributable diseases, such as alcohol-related cancers, is at least 10 years (Holmes et al., 2012). These effects could result in temporally distinct yet still related changes between PCC and changes in alcohol-related morbidities.

There are many reasons why the precision of PCC estimates matters. First, the Tax Cuts and Jobs Act of 2017 (Public Law No: 115-97) reduced excise taxes on all alcoholic beverages. A large body of evidence shows that decreases in alcohol taxes can result in increases in alcohol consumption (Wagenaar et al., 2009), which can give rise to alcohol-related morbidity and mortality (Wagenaar et al., 2010). If there is a further and continued increase in alcohol consumption by the U.S. population over age 15, then further increases in alcohol-related problems may be forthcoming, such as traffic accidents (Chang et al., 2012) and suicides (Kerr et al., 2011). Second, the recent legalization of recreational cannabis in many states is of concern in an environment of increasing alcohol use because of the negative impact of simultaneous cannabis and alcohol use, such as drunk driving, social consequences, and harms to self (Subbaraman and Kerr, 2015). Third, recent national surveys report a decline in both any alcohol use (Johnston LD, 2013) and binge drinking among youth (Keyes and Miech, 2013), suggesting that the noted increase in PCC is due to more alcohol use and binge drinking among middle-aged and older adults. Indeed, recent surveys have observed an increase in self-reported past-month binge drinking and AUD among adults aged 50 and older (Han et al., 2017), and an increase in alcohol-related emergency department visits (White, et al 2018). This is cause for concern because older adults are more likely to have various co-morbidities and to use medication that contraindicates the use of alcohol

(Moore et al., 2007). Finally, the national surveys and meta-analysis (Grucza et al., 2018) that showed an increase in binge drinking generally may be particularly concerning if the alcohol content of the beverages being consumed is higher than previously assumed as this may increase the likelihood of negative alcohol-related consequences.

This work has limitations that should be considered when interpreting our results. The estimate for PCC from wine may have been underestimated from 2012 to 2016 since we carried forward the %ABV value for 30% of total sales volume from 2011 to 2016 instead of calculating from actual wine %ABV values. This change in methodology was due to changes in the availability of data, which also highlights the challenge of this methodology to identify adequate and reliable sources of information. Relatedly, how we calculated the mean %ABV of wine by identifying the leading brands of wine based on sales in Pennsylvania only is a limitation because it does not represent sales nationally. Since only general brands and not individual brands are reported nationally it is not possible to determine if using leading individual brand sales of wine in Pennsylvania would result in an over- or underestimate of the mean %ABV of wine and thus its impact on PCC wine estimates. Regarding the %ABV of all alcoholic beverages, the %ABV value taken from producer reports or websites may not accurately reflect the actual amount of alcohol. This is less likely for spirits which are taxed based on alcohol content at the federal level, but may still be relevant for beer and wine which are not routinely tested by independent authorities, except in regard to labelling where considerable error is allowed. Regarding other components of the calculation of PCC estimates, population estimates may also represent another source of error as certain undercounted groups, often rural and/or racial/ethnic minorities, and those not included in the population such as foreign tourists and undocumented immigrants, may comprise a greater proportion of the population in recent years (U.S. Census Bureau, 2012). The alcohol sales data may also have error due to unaccounted for changes in reporting practices over time, variation by state, and the time delay between actual consumption and the publication of state tax records (Haughwout, 2018). Moreover, alcohol sales data will not include unrecorded consumption from illicit production, importation, and sales. Fortunately, unrecorded consumption is likely minimal due to substantial decreases in illicit alcohol production in the U.S. since the 1970s (Rehm et al., 2014). Similarly, cross-state sales are also present but not likely to have a significant impact on consumption estimates (Ye and Kerr, 2016). However, these factors are a reality and may introduce inaccuracies into our PCC estimates (Haughwout, 2018). Finally, the likely errors in each component of the PCC calculation, that is, the alcohol sales figures, the %ABV values, and population estimates, would result in errors in the PCC estimates. Since these error values are unknown, however, statistical tests of differences between ABV-variant and ABV-invariant PCC estimates are not feasible. It is noteworthy that the population estimates and alcohol sales data are also components of the AEDS methodology such that the same errors are included in our PCC estimates. Further, the errors in the estimates of components of the PCC calculation beyond the %ABV values represent other possibilities for improving the precision of PCC estimates, such that refinements in alcohol sales figures and population estimates could improve PCC calculations. These refinements, however, would necessitate changes in the reporting and collection of these data, which would likely be more cumbersome than including data on annual changes in %ABV values of beer, wine, and spirits.

The inclusion of time-varying %ABV in the calculation of PCC estimates showed increasing %ABVs for all beverage types, preferences for beverages with higher and increasing %ABV, and a greater increase in PCC estimates compared to those using time invariant %ABV values. PCC measures are used to explain changes in alcohol-related mortality (Jiang et al., 2018) and morbidity (White et al., 2018), for comparison of alcohol use across geographic regions (Kerr, 2010), the study of alcohol policies (Xuan et al., 2015), the examination of alcohol use over time, the calculation of global alcohol-attributable fractions, and to inform news articles about alcohol use in the U.S. (Chevalier, 2018). It is therefore critical that PCC measures are as precise as possible to ensure that conclusions drawn from the applications of these measures are accurate and valid. Through the presentation of estimates based on ABV variation and comparisons to estimates from ABV-invariant methods we suggest that the inclusion of annual estimates of the %ABV of alcoholic beverages sold in the U.S. is necessary to ensure the precision of PCC measures and the accurate detection of changes in alcohol consumption over time and place.

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