Effects of Alcohol Tax and Price Policies on Morbidity and Mortality: A Systematic Review

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Objectives. We systematically reviewed the effects of alcohol taxes and prices on alcohol-related morbidity and mortality to assess their public health impact.

Methods. We searched 12 databases, along with articles' reference lists, for studies providing estimates of the relationship between alcohol taxes and prices and measures of risky behavior or morbidity and mortality, then coded for effect sizes and numerous population and study characteristics. We combined independent estimates in random-effects models to obtain aggregate effect estimates.

Results. We identified 50 articles, containing 340 estimates. Meta-estimates were r=–0.347 for alcohol-related disease and injury outcomes, –0.022 for violence, –0.048 for suicide, –0.112 for traffic crash outcomes, –0.055 for sexually transmitted diseases, –0.022 for other drug use, and –0.014 for crime and other misbehavior measures. All except suicide were statistically significant.

Conclusions. Public policies affecting the price of alcoholic beverages have significant effects on alcohol-related disease and injury rates. Our results suggest that doubling the alcohol tax would reduce alcohol-related mortality by an average of 35%, traffic crash deaths by 11%, sexually transmitted disease by 6%, violence by 2%, and crime by 1.4%. (*Am J Public Health.* 2010;100: 2270–2278. doi:10.2105/AJPH.2009.186007)

Alcohol prices and taxes are rising issues on the agenda of state and local health officials and policymakers because of historically low real alcohol tax rates, political opposition to increased income and property taxes, increasing budget shortfalls, and positive experience with tobacco tax increases. Moreover, the knowledge base on alcohol tax effects is much larger than most health officials and policymakers realize. Over the past several decades, 162 papers have been published that evaluate the effects of alcohol tax and price levels on alcohol sales, drinking, and a range of alcohol-related morbidity and mortality outcomes. We recently presented the cumulative evidence from 112 papers containing 1003 estimates of effects of alcohol taxes and prices on alcohol sales and drinking behaviors; we found statistically significant inverse relationships for all 3 major beverages (beer, wine, and spirits).[1] The major conclusion emerging from those 112 studies was that a 10% increase in alcohol prices resulted in an approximately 5% reduction in drinking.

A large epidemiological literature covering many decades shows drinking to be a risk factor for a wide range of injuries, diseases, and social disruption,[2–4] and considerable consensus has emerged on approximate alcohol-attributable fractions for several leading causes of morbidity and mortality.[5,6] Because the link between alcohol tax and price levels and drinking (including heavy drinking) is so well established, along with the association of individual and population drinking levels with several indicators of morbidity and mortality, we hypothesized an effect of alcohol tax and price levels on morbidity and mortality. Therefore, we systematically reviewed the literature and calculated overall estimates of effect between alcohol tax or price changes and the range of alcohol-related morbidity and mortality outcomes reported in the literature.

METHODS

A doctoral student with expertise in econometric methods conducted a comprehensive search of the published literature in 12 databases: AgEcon Search (1960–2009); Blackwell-Synergy (1879–2009); EBSCO Host, which includes EconLit (1969–2009); Academic Search Premier (1922–2009); Business Source Premier (1922–2009); PsychInfo (1967–2009); JSTOR (1838–2009); MEDLINE (1950–2009); Springer (1992–2009); ScienceDirect (1823–2009); Thomson Reuters ISI Web of Knowledge (1900–2009); and Wiley (1961–2009).

Our search terms for each database were as follows, where * was the truncation indicator to include all forms of the root word: [(tax OR taxes OR taxation OR cost OR cost* OR price OR prices) AND (alcohol* OR drinking OR liquor OR drunk* OR beer OR wine OR spirits OR malt beverage*)]. Any record with any search term in the title, keywords, subject heading, descriptors, or abstract fields was identified. In addition, we located additional relevant studies in the reference lists of the selected articles.

We obtained each article and reviewed it for relevance and content. Studies were excluded from analysis if they were (1) duplicate publications of a single study or data set (most recent was retained); (2) empirical studies that did not provide sufficient data for calculating some form of numeric estimate of effect and estimate of its standard error; (3) commentaries, legal reviews, or literature reviews, or articles that for another reason reported no new data; or (4) not written in English.

Data Classification and Coding

Studies eligible for inclusion in the analyses assessed effects of alcohol prices or taxes on a range of morbidity and mortality outcomes. Much of the literature treats various tax or price indices as alternative measures of the same underlying phenomenon, especially because spatial variability and sudden changes in price over time are largely attributable to differing alcohol excise taxes.

Individual studies identified in our search had considerable variation in quality, specific

measures, research designs, and statistical models. However, all studies were conceptually similar and provided results from some sort of regression equation showing estimated coefficients and standard errors or other statistics that indicate the standard error, such as a *t* ratio or confidence interval. We coded the measure of effect, its standard error, the analysis sample size, and the effect's significance level for each separate estimate.

For studies that reported significance cutoff values (e.g., .05) but not exact values, we (conservatively) assigned the value .05, even though the (unknown) exact value was less than .05. We coded all relevant estimates from each article, including results from multiple subgroups, multiple follow-ups, and multiple statistical models for each subgroup.

Statistical Analyses

We used Comprehensive Meta-analysis 2.0 software[7] to estimate a standardized effect size *r* for each separate estimate of the underlying relationship of interest, calculated from the statistics reported in each study and preprogrammed conversion formulas from the meta-analysis statistical literature. The *r* estimates are interpretable as the standardized slope of the relationship between the independent variable and the outcome variable. We examined heterogeneity of effects and conducted sensitivity and robustness analyses to evaluate the consistency of estimates across study characteristics and risks to the meta-estimates attributable to publication bias and potential nonrepresentativeness of the sample studies.

We combined individual effect sizes in 4 steps to produce a single meta-estimate of effect for each outcome. First, we identified sets of statistically independent estimates (e.g., separate youth and adult samples, separate states) and nonindependent estimates (e.g., multiple estimation models derived from the same population or sample). Intrastudy estimates that were not independent were averaged such that only 1 value contributed to the meta-analysis. We then applied inverse variance–weighting methods to each resulting independent effect size.[8]

Second, we examined effect size distributions for outliers, to determine the need for trimming (i.e., deletion of outliers) or winsorizing (i.e., transformations to reduce effects of outliers). Next, we calculated the weighted mean effect sizes for each subgroup as $\overline{ES} = \Sigma(w_i ES_i)/\Sigma w_i$, where ES_i were the values of the effect size statistic used (here *r*), w_i was the inverse variance weight for each effect size *i*, and *i* was equal to $1 - k$, with *k* being the number of effect estimates. Last, we conducted homogeneity tests within and across subgroups with the *Q* statistic,[9] where a statistically significant *Q* indicated a heterogeneous effect size distribution.[10]

As anticipated, we observed statistically significant study-level heterogeneity and therefore adopted a random-effects model to determine the average meta-estimates of effect and their precision.[8] We constructed confidence intervals (CIs) and tested the significance of each mean effect size, where a 95% CI was $\overline{ES} \pm Z_{(.95)}(SE_{\overline{ES}})$ and the significance of the mean effect size was obtained with a *Z* test as $z = |\overline{ES}|/SE_{\overline{ES}}$.

The calculated standardized effect size *r* was not uniformly derived from reported simple bivariate estimates of the underlying relationship of interest (alcohol price/tax→outcome), because such bivariate correlations were rarely reported. We also did not calculate effects via a multiple regression model with identical model forms and covariates across studies. This procedure is inherent to any literature where a single straightforward uniform research design is not typical (by contrast with meta-analyses of a large set of similarly designed randomized clinical trials). As a result, the statistical theory and accompanying assumptions that underlie the calculation and accumulation of standardized effect sizes were not fully met. Therefore, we also reported alternative, simpler summary statistics, such as the proportion of individual estimates in the hypothesized direction and the proportion that was significant, to provide additional information about the underlying estimates.

We grouped the diverse set of outcome measures reported in the literature into 8 conceptually distinct categories: specific measures of alcohol-related disease or injury, other morbidity and mortality indicators, violence, suicide, traffic crashes and alcohol-related driving measures, sexually transmitted diseases (STDs) and risky sexual behavior, other drug use, and crime and misbehavior indicators. However, any grouping of the estimates and outcomes combined somewhat disparate outcomes and contexts. Therefore, we also calculated the effect size and specific outcome from each study separately. Obviously, differences in estimated effect size from study to study may have been attributable to the specific outcome measures used or local differences in samples and contexts of a given study.

RESULTS

We identified 50 papers containing 340 estimates of the effects of alcohol taxes or prices (Table 1).[11–60] Studies were diverse in the units analyzed (state–country aggregate vs individual-level data), outcome measures, settings, time, statistical models, independent variable measure (alcohol prices or taxes), and population (adults or youths or both). The meta-estimate of effect for all of the studies across all outcomes combined was $r=-0.071$ and was statistically significant ($Z=-12.491$; $P<.001$; Table 2). The inverse variance–weighted partial *r* for the aggregate-level studies was –0.119 ($Z=-8.769$; $P<.001$); for the individual-level studies, –0.029 ($Z=-6.244$; $P<.001$); for studies with alcohol price as the independent variable measure, –0.065 ($Z=-4.866$; $P<.001$); for studies with alcohol tax as a surrogate measure for price, –0.073 ($Z=-11.228$; $P<.001$); for studies of adults, –0.079 ($Z=-9.151$; $P<.001$); and for studies of youths, –0.069 ($Z=-7.659$; $P<.001$).

The first section of Table 2 presents the results from studies that specifically examined effects of alcohol prices or taxes on alcohol-related disease or injury. Eleven articles (reporting 13 statistically independent studies) provided 29 estimates of effect, among which 22 (76%) showed a statistically significant inverse association. At the study level, all 13 studies were in the hypothesized direction and only 2 were not significant.[23,50] The inverse variance–weighted overall *r* for the 13 studies was –0.347 and significant ($Z=-5.430$; $P<.001$).

Two articles examined effects on morbidity and mortality outcomes not specifically alcohol-related, such as all-cause mortality[16] and industrial injury,[40] providing 5 estimates of effect. All 5 estimates showed an inverse association, and 4 were statistically significant. At the study level, both were in the hypothesized direction. The inverse variance–weighted *r* for these 2 studies combined was –0.076 ($Z=-1.942$; $P=.052$).

TABLE 1—Studies in Meta-Analysis of Effects of Alcohol Taxes and Prices on Health and Social Indicators

	Outcome Category	Population	Country	Cross-Sectional Unit	No. Repeated Observations	Data Collection Period
Adrian et al. 2001[11]	Traffic	Adults	Canada	State/province	19	1972–1990
Birckmayer and Hemenway 1999[12]	Suicide	Adults and youths	United States	State/province	21	1970–1990
Chaloupka and Laixuthai 1997[13]	Traffic	Youths	United States	Individual	2	1982–1989
	Traffic	Youths	United States	Individual	1	1989–1989
Chaloupka et al. 1993[14]	Traffic	Adults and youths	United States	State/province	7	1982–1988
Chesson et al. 2000[15]	STDs/risky sex	Adults and youths	United States	State/province	15	1981–1995
Cook et al. 2005[16]	Mortality/morbidity	Adults	United States	State/province	32	1970–2001
Cook and Tauchen 1982[17]	Alcohol-related mortality	Adults	United States	State/province	16	1962–1977
Cuellar et al. 2004[18]	Crime	Youths	United States	Individual	1	1994–1997
Dee 1999[19]	Traffic	Youths	United States	State/province	16	1977–1992
Evans et al. 1991[20]	Traffic	Adults	United States	State/province	12	1975–1986
Grossman and Markowitz 1999[21]	Crime/misbehavior	Youths	United States	Individual	3	1989–1991
	Violence	Youths	United States	Individual	3	1989–1991
Grossman and Markowitz 2005[22]	STDs/risky sex	Youths	United States	Individual	1	1991–1999
Heien and Pompelli 1987[23]	Alcohol-related mortality	Adults	United States	State/province	9	1968–1977
Herttua et al. 2008[24]	Alcohol-related mortality	Adults	Finland	Country	2	2001–2005
Herttua et al. 2008[25]	Crime/misbehavior	Adults	Finland	City	2	2002–2005
	Crime/misbehavior	Adults	Finland	City	4	2002–2005
	Violence	Adults	Finland	City	2	2002–2005
	Violence	Adults	Finland	City	4	2002–2005
Jimenez and Labeaga 1994[26]	Drug use	Adults	Spain	Country	1	1980–1981
Koski et al. 2007[27]	Alcohol-related mortality	Adults	Finland	Country	783	1990–2004
Markowitz 2000[28]	Violence	Adults	United States	Individual	1	1985–1987
	Violence	Adults	United States	Individual	2	1985–1987
Markowitz 2000[29]	Crime/misbehavior	Adults	Multiple	Individual	1	1989–1992
	Violence	Adults	Multiple	Individual	1	1989–1992
Markowitz 2000[30]	Violence	Youths	United States	Individual	1	1991–1995
Markowitz 2005[31]	Crime/misbehavior	Adults	United States	Individual	3	1992–1994
	Violence	Adults	United States	Individual	3	1992–1994
Markowitz et al. 2003[32]	Suicide	Adults and youths	United States	State	24	1976–1999
Markowitz and Grossman 1998[33]	Violence	Adults	United States	Individual	1	1976–1976
Markowitz and Grossman 2000[34]	Violence	Adults	United States	Individual	1	1976–1985
	Violence	Adults	United States	Individual	2	1976–1985
Markowitz et al. 2005[35]	STDs/risky sex	Adults and youths	United States	State	21	1981–2001
	STDs/risky sex	Adults and youths	United States	MSA	20	1982–2001
Mast et al. 1999[36]	Traffic	Adults	United States	State	9	1984–1992
Matthews et al. 2006[37]	Violence	Adults	Great Britain	State/province	10	1995–2000
Mullahy and Sindelar 1994[38]	Traffic	Adults	United States	Individual	1	1988–1988
Nelson and Young 2001[39]	Alcohol-related mortality	Adults	Multiple	Country	19	1977–1995
	Traffic	Adults	Multiple	Country	19	1977–1995
Ohsfeldt and Morrisey 1997[40]	Other morbidity	Adults	United States	State	10	1975–1985
Pacula 1998[41]	Other drug use	Youths	United States	Individual	2	1979–1984
Ponicki et al. 2007[42]	Traffic	Youths	United States	State	27	1975–2001
Ruhm 1995[43]	Traffic	Adults	United States	State	14	1975–1988
Ruhm 1996[44]	Traffic	Adults and youths	United States	State	7	1982–1988
Rush et al. 1986[45]	Alcohol-related mortality	Adults	United States, Canada	State/province	28	1955–1982

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TABLE 1—*Continued*

Saffer 1997[46]	Traffic	Adults and youths	United States	City	16	1986–1989
Saffer and Chaloupka 1989[47]	Traffic	Adults and youths	United States	State	6	1980–1985
Saffer and Grossman 1987[48]	Traffic	Adults and youths	United States	State	7	1975–1981
Saffer and Grossman 1987[49]	Traffic	Adults and youths	United States	State	7	1975–1981
Schweitzer et al. 1983[50]	Alcohol-related mortality	Adults	United States	State	1	1975–1975
Sen 2003[51]	STDs/risky sex	Youths	United States	Individual	4	1985–1996
Skog and Melberg 2006[52]	Alcohol-related mortality	Adults	Denmark	Country	21	1911–1931
Sloan et al. 1994[53]	Alcohol-related mortality	Adults	United States	State	7	1982–1988
	Traffic	Adults	United States	State	7	1982–1988
	Suicide	Adults	United States	State	7	1982–1988
Smart and Mann 1998[54]	Alcohol-related mortality	Adults	Canada	Province	19	1975–1993
	Traffic	Adults	Canada	Province	19	1975–1993
Wagenaar et al. 2009[55]	Alcohol-related mortality	Adults and youths	United States	State	116	1976–2004
Whetten-Goldstein et al. 2000[56]	Traffic	Youths	United States	State	12	1984–1995
Wilkinson 1987[57]	Traffic	Adults	United States	State	5	1976–1980
Yamasaki et al. 2005[58]	Suicide	Adults	Switzerland	Country	30	1965–1994
Young and Bielinska-Kwapisz 2006[59]	Traffic	Adults and youths	United States	State	19	1982–2000
Young and Likens 2000[60]	Traffic	Adults and youths	United States	State	9	1982–1990

Note. MSA=metropolitan statistical area; STD = sexually transmitted disease.

Nine articles examined effects of alcohol taxes or prices on various measures of violence. The 9 articles reported 10 statistically independent studies. These studies provided 70 individual estimates of effect, of which 29 (41%) showed a statistically significant inverse association. At the study level, 6 reported a significant inverse association between alcohol taxes or prices and violence. The inverse variance–weighted effect across the 10 studies was significant, however (r=–0.022; Z=–3.579; P<.001).

Four articles examined effects of alcohol prices or taxes on suicide, providing 12 individual estimates of effect. Among these estimates, 5 (42%) showed a statistically significant inverse association. The inverse variance–weighted effect across the 11 independent estimates was marginally significant (r=–0.048; Z=–1.726; P=.084). Removing 1 outlier[58] increased the statistical significance of the meta-estimate (r=–0.060; Z=–2.356; P=.018).

The fifth section of Table 2 presents results from 21 articles examining effects of alcohol prices or taxes on traffic safety outcomes, with 150 individual estimates of effect. Among all estimates, 86 (57%) showed a statistically significant inverse association. All 34 independent estimates showed an inverse association between alcohol prices or taxes and a traffic outcome, with 23 estimates (68%) statistically significant. The inverse variance–weighted overall partial r for the 34 independent estimates was –0.112, which was significant (Z=–8.069; P<.001). There was 1 outlier,[11] whose removal did not affect the results (r=–0.110; Z=–8.010; P<.001).

Four articles examined the effects of alcohol taxes or prices on rates of STDs and risky sexual behavior. Thirty-seven individual estimates of effect were obtained from these 4 articles, all showing an inverse association, with 28 (76%) statistically significant. All of the 12 independent estimates showed an inverse association with rates of STDs or risky sexual behavior, and 10 (83%) were statistically significant. The inverse variance–weighted effect across the 12 independent estimates was –0.055 (Z=–4.845; P<.001).

Two articles, containing 10 estimates, examined effects of alcohol taxes or prices on other drug use (i.e., tobacco and marijuana).[26,41] All of the individual estimates showed an inverse association, and 6 (60%) were statistically significant. At the study level, both estimates were in the hypothesized direction; however, neither was statistically significant when considered alone. However, the inverse variance–weighted r for these 2 studies combined was –0.022 and was significant (Z=–2.003; P=.045).

The last section of Table 2 presents results from 5 articles on the effect of alcohol prices or taxes on various indicators of crime and misbehavior, providing 27 estimates of effect. Of the 27 estimates, 21 showed an inverse association and 18 were statistically significant. At the study level, 4 showed a significant inverse association, and 1 was in the hypothesized direction but not statistically significant.[25] The inverse variance–weighted overall partial r for the 5 studies was –0.014, which was significant (Z=–2.943; P=.003).

DISCUSSION

The aggregated results from this fairly large set of studies showed clearly that beverage alcohol prices and taxes were significantly and inversely related to all outcome categories examined: alcohol-related morbidity and mortality, violence, traffic crash fatalities and drunk driving, rates of STDs and risky sexual behavior, other drug use, and crime, with the sole exception that the estimated inverse relation with suicide was not statistically significant.

Meta-analyses inherently present average effect sizes, which may not reflect the exact effect in each specific setting; some locations experience larger effects, and others, smaller effects. The magnitude of effects in our analysis

TABLE 2—Studies in Effects of Alcohol Taxes and Prices on Health and Social Indicators

	Outcome Measure	*r* (95% CI)	*Z*	*P*
	Alcohol-related morbidity and mortality			
Cook and Tauchen 1982[17]	Cirrhosis death rate	−0.080 (−0.169, 0.009)	−1.761	.078
Heien and Pompelli 1987[23]	Cirrhosis death rate	−0.003 (−0.101, 0.094)	−0.070	.944
Herttua et al. 2008[24]	Alcohol-related acute and chronic deaths	−0.068 (−0.107, −0.028)	−3.357	.001
Koski et al. 2007[27]	No. of alcohol-related injury deaths	−0.086 (−0.155, −0.016)	−2.405	.016
Nelson and Young 2001[39]	Cirrhosis death rate	−0.183 (−0.287, −0.075)	−3.313	.001
Rush et al. 1986[45]	Cirrhosis death rate (Michigan)	−0.610 (−0.801, −0.307)	−3.545	<.001
Rush et al. 1986[45]	Cirrhosis death rate (Ontario)	−0.950 (−0.977, −0.894)	−9.159	<.001
Schweitzer et al. 1983[50]	Alcoholism morbidity and mortality	−0.133 (−0.446, 0.210)	−0.754	.451
Skog and Melberg 2006[52]	Delirium tremens death rate	−0.931 (−0.972, −0.835)	−7.072	<.001
Sloan et al. 1994[53]	Primary cause death rate	−0.539 (−0.742, −0.246)	−3.358	.001
Smart and Mann 1998[54]	Cirrhosis death rate	−0.467 (−0.760, −0.016)	−2.025	.043
Wagenaar et al. 2009[55]	Alcohol-related mortality (1983 tax change)	−0.240 (−0.404, −0.060)	−2.598	.009
Wagenaar et al. 2009[55]	Alcohol-related mortality (2002 tax change)	−0.208 (−0.376, −0.027)	−2.243	.025
Total		−0.347 (−0.457, −0.228)	−5.430	<.001
	Other morbidity and mortality			
Cook et al. 2005[16]	All-cause mortality	−0.047 (−0.095, 0.002)	−1.889	.059
Ohsfeldt and Morrisey1997[40]	Industrial injury	−0.128 (−0.223, −0.031)	−2.578	.01
Total		−0.076 (−0.152, 0.001)	−1.942	.052
	Violence			
Grossman and Markowitz 1999[21]	Sexual assault	−0.013 (−0.019, −0.006)	−3.730	<.001
Herttua et al. 2008[25]	Assault, rape, domestic arrests	−0.083 (−0.189, 0.024)	−1.520	.128
Markowitz and Grossman 1998[33]	Child abuse	−0.086 (−0.158, −0.012)	−2.294	.022
Markowitz and Grossman 2000[34]	Child abuse (adult female)	−0.067 (−0.122, −0.011)	−2.348	.019
Markowitz and Grossman 2000[34]	Child abuse (adult male)	−0.047 (−0.122, 0.028)	−1.227	.22
Markowitz 2000[28]	Spouse abuse	−0.026 (−0.059, 0.007)	−1.540	.123
Markowitz 2000[29]	Probability of victimization	−0.023 (−0.033, −0.012)	−4.234	<.001
Markowitz 2000[30]	Fights	−0.012 (−0.023, −0.002)	−2.270	.023
Markowitz 2005[31]	Alcohol-related assault	−0.002 (−0.005, 0.001)	−1.027	.304
Matthews et al. 2006[37]	Violence injury rate	−0.175 (−0.252, −0.097)	−4.329	<.001
Total		−0.022 (−0.034, −0.010)	−3.579	<.001
	Suicide			
Birckmayer and Hemenway 1999[12]	Suicide (aged 15–17 y)	0.032 (−0.030, 0.093)	0.999	.318
Birckmayer and Hemenway 1999[12]	Suicide (aged 18–20 y)	0.000 (−0.062, 0.062)	0.007	.994
Birckmayer and Hemenway 1999[12]	Suicide (aged 21–23 y)	0.010 (−0.051, 0.072)	0.333	.739
Markowitz et al. 2003[32]	Suicide (females aged 10–14 y)	−0.007 (−0.063, 0.049)	−0.260	.795
Markowitz et al. 2003[32]	Suicide (males aged 10–14 y)	−0.097 (−0.152, −0.041)	−3.393	.001
Markowitz et al. 2003[32]	Suicide (females aged 15–19 y)	−0.035 (−0.091, 0.021)	−1.219	.223
Markowitz et al. 2003[32]	Suicide (males aged 15–19 y)	−0.168 (−0.222, −0.113)	−5.929	<.001
Markowitz et al. 2003[32]	Suicide (females aged 20–24 y)	−0.049 (−0.104, 0.007)	−1.699	.089
Markowitz et al. 2003[32]	Suicide (males aged 20–24 y)	−0.170 (−0.224, −0.115)	−6.008	<.001
Sloan et al. 1994[53]	Suicide	−0.339 (−0.607, −0.001)	−1.964	.05
Yamasaki et al. 2005[58]	Suicide	0.570 (0.264, 0.772)	3.367	.001
Total		−0.048 (−0.102, 0.007)	−1.726	.084
	Traffic			
Adrian et al. 2001[11]	Alcohol-related driver motor vehicle accident; fatality rate	−0.650 (−0.853, −0.278)	−3.102	.002
Chaloupka et al. 1993[14]	Crash fatality rate (adults)	−0.195 (−0.296, −0.090)	−3.602	<.001

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TABLE 2—*Continued*

Chaloupka et al. 1993[14]	Crash fatality rate (youths)	−0.322 (−0.415, −0.223)	−6.093	<.001
Chaloupka and Laixuthai 1997[13]	Driver motor vehicle accident; fatality rate; probability of motor vehicle accident	0.125 (−0.181, −0.069)	−4.326	<.001
Dee 1999[19]	Driver and total motor vehicle fatality rate	−0.102 (−0.172, −0.032)	−2.836	.005
Evans et al. 1991[20]	Alcohol-related and total motor vehicle fatality rate	−0.127 (−0.205, −0.048)	−3.122	.002
Mast et al. 1999[36]	Driver; total motor vehicle fatality rate	−0.009 (−0.104, 0.085)	−0.194	.846
Mullahy and Sindelar 1994[38]	Probability of drunk driving (adult non-White females)	−0.026 (−0.048, −0.004)	−2.287	.022
Mullahy and Sindelar 1994[38]	Probability of drunk driving (adult non-White males)	−0.027 (−0.051, −0.004)	−2.258	.024
Mullahy and Sindelar 1994[38]	Probability of drunk driving (adult White females)	−0.008 (−0.030, 0.014)	−0.731	.465
Mullahy and Sindelar 1994[38]	Probability of drunk driving (adult White males)	−0.013 (−0.037, 0.011)	−1.084	.278
Nelson and Young 2001[39]	Total motor vehicle fatality rate	−0.066 (−0.174, 0.043)	−1.182	.237
Ponicki et al. 2007[42]	Total motor vehicle fatality rate	−0.065 (−0.119, −0.011)	−2.351	.019
Ruhm 1995[43]	Total motor vehicle fatality rate	−0.205 (−0.278, −0.131)	−5.307	<.001
Ruhm 1996[44]	Total miles motor vehicle fatality rate	−0.132 (−0.235, −0.025)	−2.415	.016
Ruhm 1996[44]	Total motor vehicle fatality rate	−0.161 (−0.263, −0.054)	−2.955	.003
Saffer and Grossman 1987[48]	Total motor vehicle fatality rate (aged 21–24 y)	−0.236 (−0.335, −0.133)	−4.399	<.001
Saffer and Grossman 1987[48]	Total motor vehicle fatality rate (aged 15–17 y)	−0.146 (−0.249, −0.039)	−2.677	.007
Saffer and Grossman 1987[48]	Total motor vehicle fatality rate (aged 18–20 y)	−0.250 (−0.347, −0.146)	−4.651	<.001
Saffer and Grossman 1987[49]	Total motor vehicle fatality rate (aged 21–24 y)	−0.169 (−0.271, −0.063)	−3.110	.002
Saffer and Grossman 1987[49]	Total motor vehicle fatality rate (aged 15–17 y)	−0.183 (−0.284, −0.077)	−3.376	.001
Saffer and Grossman 1987[49]	Total motor vehicle fatality rate (aged 18–20 y)	−0.299 (−0.393, −0.198)	−5.626	<.001
Saffer and Chaloupka 1989[47]	Night driver motor vehicle fatality rate (adults)	−0.195 (−0.304, −0.082)	−3.342	.001
Saffer and Chaloupka 1989[47]	Total motor vehicle fatality rate (adults)	−0.215 (−0.322, −0.101)	−3.678	<.001
Saffer 1997[46]	Night driver motor vehicle fatality rate (aged 15–24 y)	−0.050 (−0.107, 0.006)	−1.748	.080
Saffer 1997[46]	Total motor vehicle fatality rate (aged 15–24 y)	−0.016 (−0.073, 0.040)	−0.560	.575
Sloan et al. 1994[53]	Total motor vehicle fatality rate	−0.436 (−0.675, −0.114)	−2.600	.009
Smart and Mann 1998[54]	Alcohol-related driver; motor vehicle fatality rate	−0.373 (−0.707, 0.098)	−1.568	.117
Whetten-Goldstein et al. 2000[56]	Alcohol-related driver; total; total night motor vehicle fatality rate	−0.011 (−0.091, 0.069)	−0.267	.790
Wilkinson 1987[57]	Total motor vehicle fatality rate	−0.082 (−0.212, 0.050)	−1.216	.224
Young and Likens 2000[60]	Alcohol-related driver; total motor vehicle fatality rate (aged ≥20 y)	−0.023 (−0.121, 0.075)	−0.462	.644
Young and Likens 2000[60]	Alcohol-related driver; total motor vehicle fatality rate (aged 18–20 y)	−0.014 (−0.112, 0.085)	−0.268	.788
Young and Bielinska-Kwapisz 2006[59]	Total motor vehicle fatality rate (adults)	−0.097 (−0.162, −0.031)	−2.860	.004
Young and Bielinska-Kwapisz 2006[59]	Total motor vehicle fatality rate (youths)	−0.065 (−0.131, 0.001)	−1.930	.054
Total		−0.112 (−0.139, −0.085)	−8.069	<.001
	STDs and risky sexual behavior			
Chesson et al. 2000[15]	STD rate (females aged ≥24 y)	−0.102 (−0.180, −0.022)	−2.492	.013
Chesson et al. 2000[15]	STD rate (females aged 20–24 y)	−0.061 (−0.131, 0.010)	−1.686	.092
Chesson et al. 2000[15]	STD rate (males aged ≥24 y)	−0.123 (−0.201, −0.043)	−3.024	.002
Chesson et al. 2000[15]	STD rate (males age 20–24 y)	−0.101 (−0.171, −0.030)	−2.798	.005
Chesson et al. 2000[15]	STD rate (females age 15–19 y)	−0.032 (−0.103, 0.039)	−0.882	.378
Chesson et al. 2000[15]	STD rate (males aged 15–19 y)	−0.133 (−0.202, −0.062)	−3.687	<.001
Grossman and Markowitz 2005[22]	Birth control and condom use (females aged 14–18 y)	−0.014 (−0.032, 0.005)	−1.450	.147
Grossman and Markowitz 2005[22]	Birth control and condom use (males aged 14–18y)	−0.022 (−0.041, −0.003)	−2.306	.021
Markowitz et al. 2005[35]	Gonorrhea rate (males aged 15–19 y)	−0.061 (−0.121, 0.000)	−1.960	.05
Markowitz et al. 2005[35]	Gonorrhea rate (males aged 20–24 y)	−0.061 (−0.121, 0.000)	−1.960	.05
Markowitz et al. 2005[35]	AIDS rate	−0.023 (−0.046, 0.000)	−1.960	.05
Sen 2003[51]	Abortion rate	−0.176 (−0.306,−0.039)	−2.513	.012
Total		−0.055 (−0.078, −0.033)	−4.845	<.001

Continued

TABLE 2—*Continued*

	Other drug use			
Jimenez and Labeaga 1994[26]	Tobacco consumption	-0.022 (-0.048, 0.004)	-1.628	.104
Pacula 1998[41]	Marijuana use	-0.023 (-0.061, 0.015)	-1.168	.243
Total		-0.022 (-0.043, 0.000)	-2.003	.045
	Crime/misbehavior			
Cuellar et al. 2004[18]	Probability of detention	-0.033 (-0.058, -0.008)	-2.576	.01
Grossman and Markowitz 1999[21]	Alcohol-related property damage; arguments; police trouble	-0.015 (-0.021, -0.009)	-5.100	<.001
Herttua et al. 2008[25]	Police detainments; multiple crimes/misbehavior	-0.090 (-0.196, 0.017)	-1.650	.099
Markowitz 2000[29]	Probability of being robbery victim	-0.015 (-0.023, -0.006)	-3.320	.001
Markowitz 2005[31]	Robberies	-0.004 (-0.007, -0.001)	-2.683	.007
Total		-0.014 (-0.023,- 0.005)	-2.943	.003
Total effects (all outcomes combined)		-0.071 (-0.082, -0.060)	-12.491	<.001

Note. CI = confidence interval; STD = sexually transmitted disease. Duplicate citations reflect results from multiple independent samples reported in the same article.

varied considerably across outcomes, with the largest effect size for alcohol-related morbidity and mortality. This variation was not surprising, because the measures of alcohol-related morbidity and mortality largely represented deaths where essentially all cases were known to be specifically attributable to ethanol ingestion (e.g., alcoholic cirrhosis, delirium tremens).

By contrast, outcomes examined in studies reported in other categories all had substantial proportions related to alcohol but also included many individual cases with no alcohol involvement (e.g., overall suicide, STDs, and violence). Substantial measurement error (specifically the lack of good measures of alcohol involvement) is inherent in most of the outcome indicators in this literature; therefore, the consistency of the findings of an inverse relationship between alcohol prices or taxes and the wide range of outcomes reported is noteworthy. The natural consequence of high measurement error is underestimating the magnitude of the relationship (attenuation).[61] Results for violence, suicide, STDs, and crime outcomes were particularly likely to represent substantial underestimates attributable to measurement error, because only 2 of the 38 results included indicators of alcohol involvement, and the epidemiological literature suggests that only about a quarter of those outcomes are caused by alcohol.[5]

More generally, the pattern of results across outcomes (Table 2) showed an expected monotonic relationship between the proportion of the outcome attributable to ethanol ingestion and the magnitude of the relationship between alcohol prices or taxes and the outcome (–0.347 for cirrhosis and similar outcomes, –0.112 for traffic crashes, –0.055 for STDs, –0.022 for violence, –0.048 for suicide, and –0.014 for general crime).

Our findings are consistent with a recent meta-analysis of the literature that found substantial effects of alcohol taxes and prices on alcohol sales and drinking behavior.[1] Together with that systematic review, our results indicate that hundreds of studies over the past 4 decades reveal the basic mechanism of effect: sales and excise taxes are a major determinant of variation in retail prices of alcohol across jurisdictions and across time, price of alcoholic beverages affects sales and drinking patterns, and tax policy–induced changes in drinking are in turn reflected in rates of a range of disease, injury, and other harm indicators.

Limitations

Statistical theory for systematic reviews and meta-analyses relies on assumptions regarding comparability of research designs and analytic approaches in the underlying studies. Although such assumptions are rarely met fully in any meta-analysis, in our case the pool of studies was particularly characterized by methodological diversity, including differences in the structure of the equations used to estimate effects of alcohol taxes or prices on the outcomes of interest. Consistent with this diversity, we found considerable residual study-level variance. We therefore used random-effects models to account for the residual variance in study-level effects associated with these differences.

Although we did not exclude available unpublished studies, we did not systematically search for unpublished literature. It is well known that larger studies that detect statistically significant effects are more likely to be published,[8,62–64] published in English,[8,65] and cited by other authors[64,66]—all of which may contribute to biased meta-estimates.

We assessed these potential biases by 2 methods: failsafe N[67] and Duval and Tweedie's trim and fill.[68] The failsafe N is an estimate of the number of studies with null results that would need to be added to an analysis for the estimated effect to no longer be statistically significant. For our analysis, an additional 178 (purportedly unfound or unpublished) studies with null effects would be required to negate the statistical significance of the overall estimated effect we found. For each outcome category, the number of additional studies needed to negate the significance of effects ranged from 57 (for crime) to 1991 (for traffic outcomes).

Trim and fill uses a funnel plot in a nonparametric, iterative technique for estimating the number of missing studies that might exist in a meta-analysis and the potential effect these missing studies might have on conclusions.[68] This procedure suggested that 28 studies might have been missed in our analysis because of publication and other small-study biases; adjusting our overall random-effects partial r meta-estimate for these purported missing studies reduced the estimate from –0.071 to –0.038, which nevertheless remained statistically significant (95% CI=–0.050, –0.027). After we adjusted for publication and small-study bias, our

meta-estimates remained statistically significant for alcohol-related morbidity and mortality (r=–0.347; 95% CI=–0.457, –0.228), violence (r=–0.014; 95% CI=–0.027, –0.001), traffic outcomes (r=–0.067; 95% CI=–0.094, –0.039), STDs (r=–0.027; 95% CI=–0.050, –0.003), and crime (r=–0.011; 95% CI=–0.020, –0.002). The bias-adjusted estimate for suicide was r=–0.048 (95% CI=–0.102, 0.007).

Because we had only 2 studies each in the other morbidity and mortality and other drug use categories, we could not calculate failsafe N and trim-and-fill estimates for those 2 categories. Although small-study and publication biases likely were present, such effects would not negate the overall conclusion of a significant inverse relationship between alcohol taxes and prices and population health outcomes, with the sole exception of suicide, for which the evidence remains insufficient.

Despite methodological limitations, the overwhelming consistency of the evidence in this literature is clear. Excluding suicide, every independent estimate except 1[13] showed an inverse relationship between alcohol taxes and prices and harmful outcomes. Of 11 suicide estimates, 7 were negative and 4 were positive, perhaps suggesting that suicide operates differently as an independent estimate.

Public Health Significance

Our results establish beyond any reasonable doubt that alcohol taxes and prices are inversely associated with population health outcomes. But how significant is this apparent effect to public health? Two approaches can be taken to evaluate the substantive significance of these findings.

Effect sizes for individual-level preventive interventions are frequently reported as Cohen's d (standard mean difference), which is comparable to $2r$, and Cohen's rule of thumb is that d=0.20 is a small effect and d=0.80 is a large effect.[69] In the data we analyzed, the effect on alcohol morbidity and mortality indicators was r=–0.347, analogous to d=–0.70, a large effect, and the effect on traffic crash outcomes was r=–0.112, analogous to d=–0.22, a medium effect. Effects on crime, violence, and STDs, although still statistically significant, were smaller. In the context of individual-level interventions, some of these effects might be deemed as medium-sized effects, but in our analysis they were population-level effects. Modest effects on individuals are substantively larger and more significant when the effects apply across the entire population of drinkers in a region or country.

A second way to assess the public health significance of our findings is to estimate the percentage reduction in these important population health outcomes associated with a given change in alcohol tax. In this calculation, r represents the standardized slope, and a 1-SD change in the independent variable is associated with an r times SD reduction in the dependent variable. We assessed several data sets on alcohol taxes and alcohol-related mortality indicators for the United States and found that SDs (estimated longitudinally over many years or cross-sectionally across the 50 states) are approximately equal to the mean. Therefore, an alternative interpretation of r is that it is the proportionate reduction in morbidity or mortality associated with doubling the alcohol tax. According to the data we analyzed, doubling alcohol taxes would be associated with an average reduction of 35% in alcohol-related mortality, an 11% reduction in traffic crash deaths, a 6% reduction in STDs, a 2% reduction in violence, and a 1.2% reduction in crime.

Conclusions

In most developed countries, alcohol is second only to tobacco as a consumer product that causes death (approximately 85 000 alcohol-related deaths per year in the United States alone[70]); the public health significance of our findings is therefore obvious. Moreover, by contrast to many prevention efforts, the mechanisms for taxing alcoholic beverages are already in place, and the large public health benefits not only accrue without requiring additional fiscal resources, but actually generate additional revenues that can be used for other pressing public health infrastructure and prevention needs. ■

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Contributors

A.C. Wagenaar originated, designed, and supervised the study and obtained funding; acquired the data and took responsibility for its integrity; conducted the statistical analysis; and drafted the article and revised it for important intellectual content. A.L. Tobler conducted the statistical analysis and drafted the article. K.A. Komro originated and designed the study and revised the article for important intellectual content. All authors analyzed and interpreted the data.

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Human Participant Protection

No protocol approval was required because no human participants were involved.

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