Received: 10 August 2021 | Accepted: 14 July 2022
DOI: 10.1111/add.16011

RESEARCH REPORT

ADDICTION SSA

Alcohol sales in Canadian liquor outlets as a predictor of subsequent COVID-19 infection rates: a time-series analysis

Tim Stockwell[1] | Jinhui Zhao[1] | Fariha Alam[1,2] | Sam Churchill[1] | Yipu Shi[3] | Timothy Naimi[1]

[1]Canadian Institute for Substance Use Research, University of Victoria, Victoria, BC, Canada
[2]Dalla Lana School of Public Health, University of Toronto, Toronto, Ontario, Canada
[3]Public Health Agency of Canada, Ottawa, Ontario, Canada

Correspondence
Tim Stockwell, Canadian Institute for Substance Use Research, University of Victoria, PO Box 1700 STN CSC, Victoria, BC, Canada, V8P 2Y2.
Email: timstock@uvic.ca

Funding information
Institute of Population and Public Health, Grant/Award Number: 423809; Public Health Agency of Canada; Centre for Addiction and Mental Health

Abstract

Aims: Government alcohol sales data were used to examine whether age 15+ per-capita alcohol consumption (PCAC) (i) changed during COVID-19 and (ii) predicted COVID-19 infections 2–5 weeks later.

Design: Interrupted time-series analyses were applied to panels of data before and after COVID-19 restrictions were introduced in Canada.

Setting and participants: The populations, aged 15+, of the provinces of Ontario (ON), British Columbia (BC) and Nova Scotia (NS), Canada.

Intervention: Expansion of home delivery options and hours of trading for liquor stores while restrictions on travel, social and economic activities were imposed by governments during COVID-19 from 17 March 2020 until 29 March 2021.

Measurements: Weekly estimates of (i) age 15+ PCAC using sales data supplied by provincial government alcohol distributors for liquor stores, bars and restaurants, (ii) stringency of public health measures assessed by the Public Health Agency of Canada (PHAC) and (iii) new COVID-19 infections reported by PHAC.

Findings: PCAC increased by 7.10% (P = 0.013) during the pandemic versus previous years, with increased private liquor store sales partly offset by reduced bar/restaurant sales. Consumption was positively associated with stringency of public health measures. Weekly PCAC was positively associated with new COVID-19 infections 2 weeks later (+6.34% for a one drink/week increase, $P < 0.001$). Lagged associations with COVID-19 infections 2 or 3 weeks later were observed for PCAC from all sales channels, with larger effect sizes per standard drink/person/week increase for on-premise outlets (+77.27% week 2, P = 0.009) than government liquor stores (+6.49%, week 2, $P < 0.001$) or private liquor stores (+7.13%, week 4, $P < 0.001$).

Conclusions: Alcohol consumption increased in three Canadian provinces during COVID-19 to degrees corresponding to the extent of the strictness of measures imposed to prevent viral spread. Increased consumption of alcohol was associated with increased COVID-19 infection rates 2 weeks later.

KEYWORDS
Alcohol policy, alcohol use, Canada, COVID-19 prevention, per capita alcohol, public health policy

INTRODUCTION

Alcohol is the most widely used legally available recreational substance among Canadians [1]. The harms associated with alcohol use in Canada are high, with more than 18 000 deaths, 105 000 hospital admissions and more than 700 000 Emergency Room presentations estimated for the year 2017 [2]. By comparison, during the first 12 months of the pandemic, COVID-19 contributed to approximately 20 000 deaths and 40 000 hospital admissions [3].

In this paper we take advantage of access to detailed alcohol sales data from three Canadian government liquor distribution monopolies to explore how alcohol consumption levels changed during the public health restrictions introduced from 17 March 2020 following the World Health Organization's declaration of a global pandemic on 11 March 2020 [4]. Changes in alcohol consumption levels have implications for the extent of alcohol-related harms in a population and hence also the burden placed on health-care services, a special concern during a pandemic [5].

Alcohol consumption itself is a risk factor for the spread of COVID-19 infections by virtue of some high-risk contexts in which it is consumed (e.g. private functions, social gatherings, bars, restaurants) and by its demonstrated role in reducing social distancing [6]. We thus also explore in this paper whether relationships can be observed between levels of alcohol consumption in a population and later rates of COVID-19 infections. Given delays between both wholesale and retail alcohol purchases and actual alcohol consumption, on one hand, and the time to develop and have confirmed a COVID-19 infection (up to 2 weeks) [7] on the other, we investigated whether positive lagged associations would be found between alcohol consumption and rates of new infection between 2 and 5 weeks later.

Canadian and US jurisdictions quickly declared that off-premise alcohol sales were 'essential', together with groceries, pharmaceuticals and fuel. One justification provided by government spokespeople in several North American jurisdictions [8–10] was to protect health-care resources from being overwhelmed by people going into alcohol withdrawal. Close analysis of the process of decision-making in California revealed the key role of the alcohol industry in promoting this narrative [8]. In fact, for Canada only approximately 5% of alcohol-attributable hospital admissions involve alcohol withdrawal [5].

World-wide, analyses of sales and self-report survey data reveal a range of impacts on levels of alcohol consumption reflecting different policy measures and different economic conditions. Surveys in the United Kingdom, Ireland and Germany indicate increased consumption, but no changes or decreases in other European countries [11]. In Canada, respondents to a national survey were more likely to report increasing alcohol use during the first lockdowns imposed [12]. An analysis of beer sales in Australia suggested increased consumption during the first lockdown [13]; elsewhere, alcohol consumption was reduced by targeted restrictions on alcohol production and sale, e.g. Mexico [14], India [15] and South Africa [16].

We hypothesized that policies introduced in Canadian jurisdictions to ensure continued convenient access to off-premise alcohol (accounting for 80% of alcohol sales in Canada), with more accessible home delivery options for some manufacturers and retailers plus longer hours for some sales channels, would contribute to increased consumption overall during the lockdowns imposed during the COVID-19 pandemic. In British Columbia (BC) and Ontario (ON), liquor store hours increased from 98 to 112 hours per week and same-day home delivery options were introduced, directly from stores, restaurants and also through third-party delivery services such as UberEats [17, 18]. Previously, home delivery was limited to some liquor stores and involved delays of several business days [19]. Nova Scotia (NS) expanded opportunities for online sales and home deliveries from breweries (with discounts for 12 packs). ON also reduced minimum prices for spirits with an alcohol content greater than 14.8% by volume [20].

Underlying mechanisms for increased consumption could also be psychological in terms of increased stress experienced by some people during lockdown [21], but also economic because of shifts towards purchasing cheaper alcohol from off-premise outlets. We hypothesized that increased stringency of all public health measures to combat COVID-19 had the common effects of restricting people to their homes while also increasing levels of stress, thus providing both more motivation and opportunity for increased alcohol consumption. Finally, we predicted positive associations between levels of alcohol consumption and subsequent rates of new COVID-19 infections, with earlier associations for estimates made with retail sales from government stores than from wholesale sales to privately owned liquor stores, bars and restaurants. In summary, the research aimed to address the following questions relating to age 15+ PCAC, in total and by alternative sales channels:

i. Did PCAC change during the first 12 months of the COVID-19 pandemic compared with previous years after controlling for seasonal effects, autocorrelation, moving averages, region and any pre-COVID trends?
ii. Was the degree of the change in PCAC associated with the stringency of overall public health measures?
iii. During the first 12 months of the pandemic, was weekly age 15+ PCAC associated with changes in rates of new COVID-19 infections at lag weeks 2–5 after adjustment for region, pre-trend and season, autocorrelation, moving averages and stringency of public health measures?

METHODS

Design

Interrupted time-series designs [22] were used to address each research question using weekly panels of data on per-capita alcohol consumption (PCAC), the stringency of applicable public health measures and rates of new COVID-19 infections for the provinces of BC, ON and NS. Auto-regressive integrated moving average (ARIMA) models [23, 24] were used to analyse the panels of weekly time-series data for each of three provinces separately, with 154 pre-intervention observation weeks for BC and ON, 258 for NS and 54 post-intervention observations for all. The intervention was the declaration of a national emergency in Canada on 17 March 2020 and subsequent public health measures up to 29 March 2021 before the national vaccination programme was fully under way. Mixed linear regression models were also used to analyse the pooled data from all three provinces [25–27], with 566 pre-intervention and 162 post-intervention observation weeks. Further details of the models are provided below and in Supporting information, Appendix B. In the final model, testing associations between weekly PCAC and lagged rates of new infection, 162 pandemic period observation weeks were analysed from 17 March 2020 to 29 March 2021. The study protocol was not pre-registered and so the analyses should be considered exploratory.

Data sources

Alcohol sales

Weekly retail alcohol sales in litres of pure alcohol were provided by the BC Ministry of Public Safety and Solicitor General Liquor Distribution Branch (LDB), the NS Liquor Commission (NSLC) and the Liquor Control Board of ON (LCBO), each of which regulate the distribution, importation and retailing of beverage alcohol in their province. While requests for these data were made to all 10 Canadian provinces and three territories, only these three provinces were able or willing to provide the very detailed sales data required. The estimates were then converted to weekly standard drinks (standard drinks = 17.05 ml or 13.45 g ethanol) per adult aged 15+ using Statistics Canada population data [28, 29], i.e. PCAC for the years 2015 to 2021 for NS and 2017 to 2021 for ON and BC, thus creating a total of 312 weekly observations for NS and 208 for BC and ON.

There were limitations in the sales data provided by the LCBO for ON which were overcome by further estimation procedures. First, missing data for 1 week in May, 2020 were estimated taking mid-points of data points immediately before and afterwards. Secondly, the LCBO could not provide data on beer sales from private beer stores which account for almost two-thirds of beer sales in ON [30]. These missing data were estimated by comparing the LCBO data with comprehensive Statistics Canada reports of total off-premise beer sales and assuming that the difference for each time-period was made up by private beer store sales. The exact procedures used for these calculations are provided in Supporting information, Appendix A. As a sensitivity test, all analyses were conducted with and without ON data to determine if the pattern of results was markedly different.

COVID-19 infection data

The data on new COVID-19 infections were obtained from Canadian government sources [31]. Weekly rates of new infections per 100 000 people were calculated for each province between 17 March 2020 and 29 March 2021 to match the weekly age 15+ PCAC estimates.

Population data

Population data for each province were estimated and projected by Statistics Canada [28]. We used the spline method [32, 33] to estimate weekly total population and population aged 15+ for the study period. The data were used to calculate weekly age 15+ PCAC and weekly rates of new infections per 100 000 population.

Measure of public health restrictions

The Public Health Agency's (PHAC) COVID-19 stringency index [34], adapted from the University of Oxford's stringency index [35], was used as a continuous measure of the restrictiveness of the general lockdown policies in each province. The PHAC stringency index combines, quantifies and updates daily information on school closures, work-place closures, cancellation of public events, restrictions on gathering size, closures of public transport, stay-at-home requirements, restrictions on internal movement, restrictions on international travel and public information campaigns. The average stringency index score across all domains (range = 0–100) was calculated for each week during the observed pandemic period corresponding to the weeks for which alcohol sales data were provided in each province. It was assumed that all categories of restrictions potentially created conditions that would encourage increased alcohol consumption, whether by increasing opportunity (through increased convenience and affordability) or change in motivation (increased stress).

Statistical analysis

Descriptive statistical analyses were performed to present estimates of weekly PCAC, infection rates and stringency scores in each individual province (see Supporting information, Appendix C). For research questions (i) and (ii), ARIMA [23, 24] analyses were used with panels of data from each individual province to model (a) changes in age 15+ weekly PCAC from before to after the start of the observed pandemic period; and (b) the association of these changes with the 'stringency' of contemporaneous public health measures during the observed pandemic period, again in each province separately. See Supporting information, Appendix B for the precise equations used in each case.

Mixed linear regression models [25–27] were also used to analyse the pooled weekly PCAC drawn from all three provinces to address each of the three research questions. For questions (i) and (ii), the time-series started on 4 April 2017 for BC and ON and 7 April 2015 for NS. For research question (iii) the data series began on 17 March 2020, i.e. after infections began to be reported. For all three research questions the data series ended on 29 March 2021 for all three provinces. Mixed models provide straightforward but flexible methods for assessing regional and temporal dynamics of longitudinal panels of data to model associations with (a) pooled weekly age 15+ PCAC and (b) rates of pooled new weekly infections. The equations used for the mixed models can be found in Supporting information, Appendix B.

The following procedures were applied in all interrupted time-series models reported here. First, the seasonal index method [36] was used to de-seasonalize the age 15+ PCAC data. The seasonal index was created by dividing each observation by the corresponding centred moving average [36, 37], an appropriate method used in previous published studies [38, 39]. Log-transformations were applied to correct for significantly skewed distributions and make the variance stationary for dependent variables [40], and also de-emphasize outliers [41]. The Durbin–Watson test [42] and the sample autocorrelation function plot (ACF) [43] were first used to test potential autoregressive and/or moving-average parameters for possible inclusion in models in order to control for their autoregressive and/or moving-average effects. We also used the augmented Dickey–Fuller (ADF) unit root test to confirm the stationarity of the de-seasonalized natural log-transformed time-series data in each province before implementing the ARIMA models. The sandwich estimation was used to estimate the 95% confidence interval (CI) to correct for heteroscedasticity [44]. The fully adjusted estimates from multi-level linear regression models controlled for the effects of trend change, seasonality (seasonal index method) and autoregressive moving-average within regions and over time and unobserved factors [45]. The Ljung–Box χ^2 test statistic was applied to the residuals series to confirm that they were uncorrelated, the values for these tests can be found in Table B1 in Supporting information, Appendix B. The *t*-test was used to test the significance of effects of interest. The likelihood ratio test was used to assess the model fit [46].

For the mixed models estimating lagged associations between PCAC and weekly infection rates, the natural log-transformed weekly infection rate was modelled and thus the coefficients of the exposure (i.e. weekly age 15+ per-capita standard drinks) can be interpreted as the percentage change in the infection rates for an additional standard drink per person 15+ per week after adjusting for the confounding effects of stringency index scores, linear trend and non-stationarity variance (by analyzing natural log-transformed rates). We also tested and specified the terms that represent autoregressive and/or moving average effects to adjust for these effects. Sensitivity tests were also performed for these analyses restricted to the provinces of British Columbia and Nova Scotia, given that private beer store sales were not available for Ontario.

We conducted all statistical analyses using SAS version 9.4 [47]. The SAS PROC ARIMA procedure was used to model time-series of weekly age 15+ per-capita alcohol consumption in each province and the SAS PROC MIXED procedure was used to model the pooled time-series data of alcohol consumption and infection [26].

RESULTS

Descriptive statistics for key variables

Descriptive statistics (means, standard deviations and ranges) are summarized for the whole period of the study for each of the key variables in Supporting information, Appendix C (Table C1 and Figs C1 and C2). Estimates of weekly age 15+ PCAC followed similar patterns across the provinces, with slightly lower levels for ON and mostly higher for BC. Weekly rates of new COVID-19 infections were similar for ON and British BC but substantially lower in NS.

Associations between COVID-19 restrictions and PCAC

The public health restrictions introduced to limit the spread of COVID-19 followed a very similar pattern across the three provinces (Figs 1–3). The first phase saw the abrupt introduction of the strictest restrictions which were then gradually eased during the summer months, but then ramped up during the second wave of infections in late 2020.

Across the provinces, it was estimated that total age 15+ PCAC increased by 7.10% (8.335 versus 8.927, *t*-test $P = 0.013$) during the

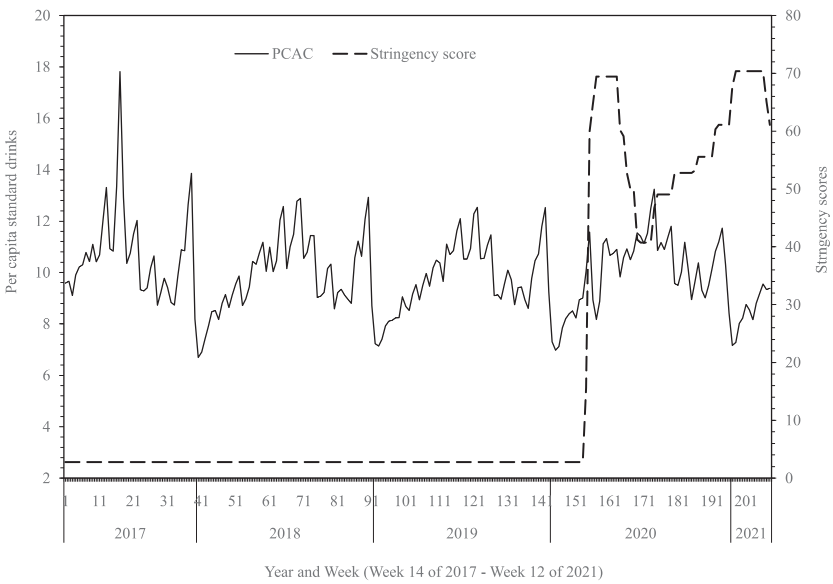

FIGURE 1 Per capita standard drinks and stringency scores weekly in British Columbia during the study period

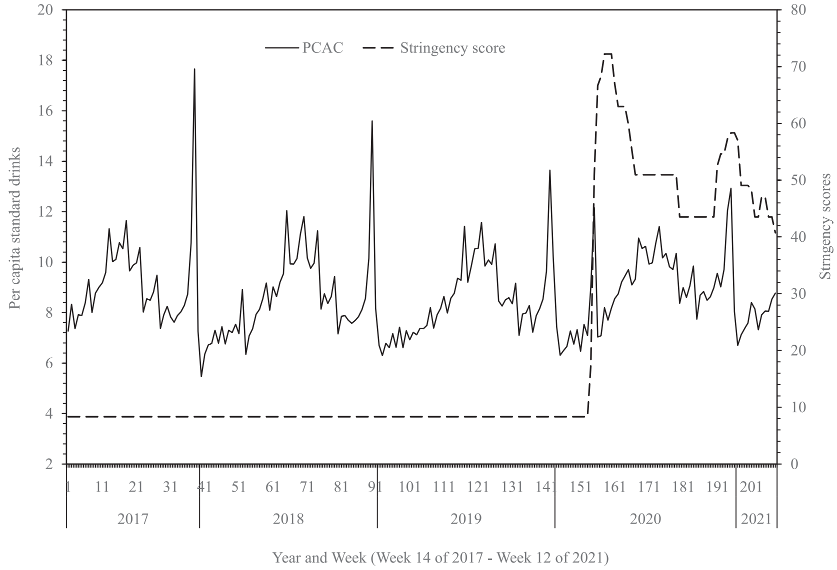

FIGURE 2 Per capita standard drinks and stringency scores weekly in Nova Scotia during the study period

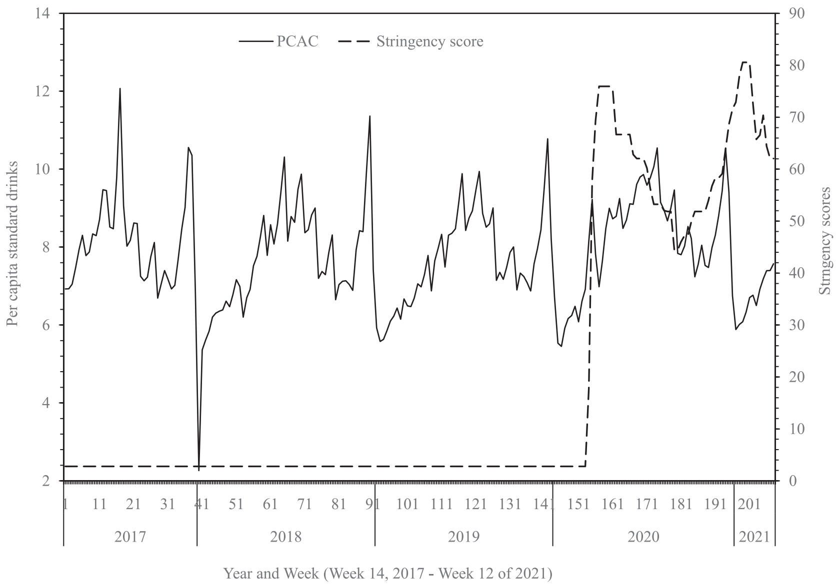

FIGURE 3 Per capita standard drinks and stringency scores weekly in Ontario during the study period

COVID-19 pandemic versus the prior period after adjustment for seasonal, trend, autoregressive and moving average effects (Table 1). Greater changes were observed in ON (+6.65%, $P < 0.001$) and NS (9.32%, $P < 0.001$) than in BC (+2.01%, $P < 0.001$). Off-premise consumption increased significantly overall in both government and privately owned liquor stores but with much larger increases for private (21.67%, $P = 0.001$) than for government-owned (8.34%, $P = 0.014$). Conversely, on-premise alcohol consumption (mainly in bars and restaurants) decreased markedly (−70.11%, $P < 0.001$).

There were significant positive associations between the strictness of public health measures (stringency score) and changes in age 15+ PCAC from off-premise outlets, but with larger effects for private compared with government-owned liquor stores (Table 2). For all provinces there were large negative associations between stringency score and a unit change (=1 standard drink per person age 15+ per week) in PCAC from on-premise outlets, i.e. bars and restaurants. The size of the overall association between changes in stringency scores and in PCAC ranged between a 0.77% increase in PCAC per standard drink per person per week in BC to a 1.45% increase for NS.

Lagged associations between PCAC and COVID-19 infection rates

Significant positive lagged associations were observed, mostly at week 2, between changes in PCAC and rates of new COVID-19 infections, as hypothesized (Table 3). A 6.34% increase in COVID-19 infection in population rates of new infections was estimated at lag week 2 (*t*-test $P < 0.001$) for one additional standard drink per person per week. As predicted, the lagged effect for private liquor stores was later (week 4) than for government liquor stores. A much larger percentage change was observed at lag week 2 (77.27%,

TABLE 1 Percentage of changes in mean age 15+ per-capita alcohol sales (standard drinks/week) in total and by outlet type for BC, Ontario and Nova Scotia before and during the COVID-19 pandemic.

Time period	*n* weeks	% Change[a]	Mean drinks/ week[b]	95% CIs Lower	Upper	*t*-test *P*
Government-owned liquor stores (GLS) sales, all provinces						
Pre-COVID (from 7 January 2015)	566	–	4.604	4.386	4.833	ref
COVID-19 (from 17 March 2020)	162	**8.34%**	4.988	4.881	5.097	**0.0140**
Privately owned liquor store (PLS) sales, all provinces						
Pre-COVID (from 7 January 2015)	566	–	2.247	2.113	2.389	ref
COVID-19 (from 17 March 2020)	162	**21.67%**	2.734	2.660	2.810	**0.0013**
On-premise sales (bars and restaurants), all provinces						
Pre-COVID (from 7 January 2015)	566	–	0.783	0.166	3.708	ref
COVID-19 (from 17 March 2020)	162	**−70.11%**	0.234	0.117	0.469	**0.0001**
Total recorded age 15+ alcohol sales, all provinces						
Pre-COVID (from 7 January 2015)	566	–	8.335	8.006	8.678	ref
COVID-19 (from 17 March 2020)	162	**7.10%**	8.927	8.767	9.089	**0.0125**
Total recorded age 15+ alcohol sales, British Columbia						
Pre-COVID (from 4 April 2017)	154	–	9.906	9.865	9.947	ref
COVID-19 (from 17 March 2020)	54	**2.01%**	10.105	10.035	10.176	**0.0001**
Total recorded age 15+ alcohol sales, Ontario						
Pre-COVID (from 4 April 2017)	154		8.553	8.535	8.571	ref
COVID-19 (from 17 March 2020)	54	**6.65%**	9.122	9.080	9.164	**0.0001**
Total recorded age 15+ alcohol sales, Nova Scotia						
Pre-COVID (from 7 April 2015)	258		7.347	7.330	7.363	ref
COVID-19 (from 17 March 2020)	54	**9.32%**	8.032	8.002	8.063	**0.0001**

Note: Results that reach the p < 0.05 or 5% level of statistical significance are in bold.
[a]% change of adjusted mean standard drinks in each time-period versus pre-COVID-19 period.
[b]Standard drinks per adult aged 15 + per week after adjusting for seasonality (deseasonalized using seasonal index method), trend dependence (pre-trend 1, 2, 3, …, 154, 155, …, 155 in BC and ON and pre-trend 1, 2, 3, …, 258, 259, …, 259 in NS), autoregressive and/or moving average effects and change of variance over time (natural log-transformation method). CI = confidence interval.

TABLE 2 Percentage of changes in age 15+ per-capita sales in total and by outlet type across three Canadian provinces for a 10-point increase in stringency score (0–100).

Alcohol sales category	*n* weeks	Drinks/week[a]	% Change[b]	Adjusted change in drinks[c]	95% CIs Lower	Upper	*t*-test *P*
Government stores	728	5.289	1.11	1.011	1.010	1.012	0.0001
Private stores	728	2.695	2.84	1.028	1.026	1.031	**0.0001**
Bars/restaurants	728	0.828	−10.30	0.897	0.886	0.909	**0.0001**
Total sales, all provinces	728	8.814	0.88	1.009	1.006	1.012	**0.0021**
Total sales, BC	208	9.989	0.77	1.008	1.005	1.010	**0.0097**
Total sales, NS	312	8.681	1.45	1.015	1.012	1.017	**0.0001**
Total sales, ON	208	7.838	1.16	1.012	1.008	1.016	**0.0027**

Note: Results that reach the p < 0.05 or 5% level of statistical significance are in bold.
[a]Drinks = standard drinks per adult aged 15+ across three provinces from 4 April 2017 in BC and ON and 7 April 2015 in NS to 29 March 2021.
[b]% Change in standard drinks/week for a 10-point increase in stringency index score.
[c]Change in mean standard drinks per week after adjusting for seasonality (deseasonalized using seasonal index method), trend dependence (pre-trend 1, 2, 3, …, 154, 155, …, 155 in BC and ON and pre-trend 1, 2, 3, …, 258, 259, …, 259 in NS), autoregressive and/or moving average effect, and change of variance over time (natural log-transformation method). CI = confidence interval.

TABLE 3 Percentage change in new weekly COVID-19 infection cases per 100 000 population for one extra standard drink per person aged 15+ by outlet type in British Columbia, Nova Scotia and Ontario, 17 March 2020–29 March 2021).

	Partially adjusted % change[a]				Fully adjusted % change[b]			
Lag week	%[‡]	95%	CI	t-test *P*	%[‡]	95%	CI	t-test *P*
Total recorded alcohol sales								
Week lag 0	**−10.58**	**−17.06**	**−4.10**	**0.0015**	−8.68	−17.77	0.42	0.0614
Week lag 1	−1.67	−5.43	2.10	0.3829	−2.34	−5.69	1.02	0.1517
Week lag 2	**6.73**	**5.52**	**7.95**	**0.0001**	**6.34**	**4.45**	**8.24**	**0.0001**
Week lag 3	−1.28	−5.11	2.55	0.5097	−1.34	−4.77	2.09	0.4409
Week lag 4	−0.33	−5.60	4.94	0.9025	−0.68	−7.04	5.69	0.8340
Week lag 5	−2.97	−7.83	1.88	0.2282	−3.22	−8.29	1.85	0.2117
Government liquor store sales								
Week lag 0	**−9.55**	**−18.39**	**−0.71**	**0.0345**	−4.38	−23.63	14.87	0.6540
Week lag 1	−2.22	−12.14	7.70	0.6594	−3.56	−13.33	6.20	0.4722
Week lag 2	**6.92**	**4.03**	**9.81**	**0.0001**	**6.49**	**4.28**	**8.70**	**0.0001**
Week lag 3	0.09	−4.45	4.62	0.9693	−0.01	−4.24	4.21	0.9948
Week lag 4	2.41	−6.58	11.40	0.5973	2.24	−6.77	11.25	0.6237
Week lag 5	−1.59	−3.30	0.13	0.0693	−1.95	−10.88	6.98	0.6670
Private liquor store sales								
Week lag 0	**−16.37**	**−16.63**	**−16.10**	**< 0.0001**	**−13.84**	**−15.08**	**−12.60**	**< 0.0001**
Week lag 1	**7.33**	**1.53**	**13.12**	**0.0135**	3.98	−1.03	8.99	0.1184
Week lag 2	**7.13**	**1.52**	**12.73**	**0.0131**	−0.56	−9.50	8.38	0.9020
Week lag 3	−3.74	−8.18	0.69	0.0975	−3.80	−9.24	1.64	0.1695
Week lag 4	**6.84**	**3.01**	**10.66**	**0.0005**	**7.13**	**3.68**	**10.57**	**<0.0001**
Week lag 5	−8.87	−21.12	3.38	0.1545	−9.72	−25.81	6.38	0.2348
On-premise sales (bars and restaurants)								
Week lag 0	**−247.01**	**−392.06**	**−101.96**	**0.0010**	**−160.12**	**−301.55**	**−18.69**	**0.0268**
Week lag 1	**−36.64**	**−63.02**	**−10.26**	**0.0068**	9.58	−8.33	27.49	0.2921
Week lag 2	26.73	−37.32	90.78	0.4110	**77.27**	**19.60**	**134.94**	**0.0090**
Week lag 3	26.43	−66.60	84.69	0.8136	21.74	−39.84	83.31	0.4866
Week lag 4	**68.29**	**7.40**	**129.18**	**0.0282**	57.19	−120.84	235.23	0.5266
Week lag 5	13.03	−6.58	32.63	0.1912	20.60	−49.19	90.39	0.5607

Note: Results that reach the p < 0.05 or 5% level of statistical significance are in bold.
[a]Mixed linear regression model of natural log-transformed weekly infection rates to estimate associations of alcohol consumption on lagged infection rates adjusted for time-trend, variance non-stationary (by analyzing natural log-transformed rate) and autoregressive moving average effects.
[b]Further adjusted for stringency index score. CI = confidence interval.

$P < 0.009$) for a change of one standard drink per person per week through on-premise sales, but this was estimated from a much smaller overall volume of sales. By contrast, significant negative concurrent associations (i.e. week zero) were observed both for private liquor store sales (−13.84%, $P < 0.001$) and on-premise sales (−160.12%, $P = 0.027$).

Table D1 in Supporting information, Appendix D shows that the effect sizes expressed as elasticities were moderate for overall consumption (0.507 or 5.07% increase due to 10% increase in PCAC at week 2, $P = 0.0005$), for off-premise outlets (0.377 at week 2 for government stores, 0.538 for privately owned stores at week 4, $P < 0.001$ and $P = 0.011$, respectively) and for on-premise sales (0.638 at week 2, $P = 0.043$), despite the large effects for a unit change in consumption of one standard drink per person per week, reflecting the much lower volumes of alcohol sold through on-premise outlets during the pandemic.

Tables E1 and E2 in Supporting information, Appendix E present sensitivity tests in which only observations for BC and NS were included. These show highly consistent but larger effect sizes for the same weekly lags as in Tables 3 below (and in Supporting information, Table C2) in which data from ON were also included.

DISCUSSION

An increase in age 15+ PCAC was observed in the three provinces providing detailed alcohol sales data with an average effect of +7.10%, consistent with previous Canadian surveys (e.g. [12]).

Consistent patterns were observed throughout the three provinces, with the greatest increases corresponding to the strict lockdown measures imposed during the first few months of the pandemic. The size of the overall annual increase in PCAC was smaller in BC (+2.01%), perhaps reflecting the absence of tourism during much of 2020, with BC normally having the highest rates of tourism [48]. There were substantial shifts in the patterns of alcohol sales from on-premise (bars and restaurants) to off-premise outlets, with the private off-premise sector benefiting the most. This probably reflects special measures made by governments to protect the private liquor store sector at a time when, immediately prior to COVID-19, pressures to privatize liquor distribution and sale had been mounting in Canada [49].

The hypothesis that increases in alcohol consumption would be positively related to the extent and strictness of all public health measures imposed was supported. It is important to note that the PHAC COVID-19 stringency score was based on a wide array of restrictions on the movement of people and imposition of social distancing requirements without any specific focus on liquor policies [6]. In practice, however, lockdowns frequently targeted on-premise liquor outlets because of such clear risk factors as groups of strangers meeting each other indoors as well as evidence that bars, restaurants and large social occasions are high-risk contexts for the spread of infection [50]. These associations were observed consistently throughout the three provinces.

Plausible mechanisms for the observed increases in alcohol consumption with evidence in the literature include stronger motivation to consume alcohol for some people to deal with stress during the pandemic [21], increased convenience of access by virtue of home delivery of alcohol (amplified by the emergence of third-party delivery services) plus extended hours of off-premise trading [5], and greater affordability of alcohol by virtue of the observed shift towards lower-priced sales from off-premise rather than on-premise outlets.

Positive and significant associations between level of alcohol consumption and subsequent rates of new infections were observed through all sales channels variously at lag weeks 2 or, in the case of private stores, at 4 weeks. The later effect for private stores was expected, given that the government store sales document final retail purchases whereas the private store sales are recorded when the private store purchases more alcohol from the government liquor distributor, i.e. not when purchased by the consumer. The strong negative correlations at lag week zero, both for private stores and bars/restaurants, were unexpected. One explanation could be that people were less likely to socialize and hence drink, whether in public or private settings, when the much-publicized daily new infection rates were relatively high.

While the consumption of alcohol itself may directly increase COVID-19 risk behaviours (e.g. through reduced social distancing), it is also likely that alcohol sales are an excellent general indicator of socializing, itself an inherently risky activity during a pandemic involving an airborne respiratory virus. We acknowledge that other general non-social activities will contribute to the risk of infection and may therefore confound the observed relationships to some extent.

We acknowledge a number of other study limitations. It was necessary to estimate weekly sales of beer in ON from private stores using a different methodology. While the data sources used for this specific estimation were authoritative, it was still necessary to impute sales for private beer stores in ON by triangulating data on total beer sales and those from non-private sources. However, sensitivity tests in which data from ON were excluded found consistent patterns of results. Other sources of unrecorded consumption such as home-made alcohol and travellers' imports were not available—either before or during the pandemic. For home-made alcohol, this shortcoming would apply to the data series both before and during the pandemic, while travellers' imports are a very small proportion of unrecorded sales [47]. We also note that the associations consistently observed were highly significant. It is possible that the impact of the restrictions measured by the stringency index decayed over time with weaker effects on people's activities. Because only three provinces provided us with the data on alcohol sales we cannot be sure that these findings are generalizable to Canada's other seven provinces and three territories. However, we note that we have Canada's largest province (ON) included, as well as one western and one eastern province, with approximately 57% of Canada's population represented as a result.

CONCLUSIONS

We conclude that alcohol consumption increased in three Canadian provinces during COVID-19 to degrees corresponding to the extent of the strictness of measures imposed to prevent viral spread. We also conclude that increased consumption of alcohol was associated with increases in rates of new COVID-19 infections 2–4 weeks later.

As in many developed countries, Canadian policy on alcohol during COVID-19 combined a continued, convenient and affordable off-premise supply together with heavy restrictions for on-premise consumption. The net result was an overall increase in consumption which placed upward pressure on rates of new infections, and hence demand for health-care, despite the restrictions placed on bars and restaurants. It follows that policies to reduce population consumption of alcohol would probably have strengthened the public health response to containing the COVID-19 pandemic, i.e. by placing price and availability restrictions on off-premise as well as on-premise sales. Such policies should also be considered during the recovery period rather than perpetuating the new relaxed alcohol policies. Examples of such policies include minimum unit pricing (MUP) for alcohol and increased alcohol taxes. MUP can help governments increase revenues while supporting both off-premise and on-premise outlets to make greater profits while selling less alcohol [5]. There are now many examples of Canadian governments making the relaxed alcohol policies introduced during the pandemic permanent (e.g. [17, 18]).

ACKNOWLEDGEMENTS

We are indebted to multiple agencies and individuals who helped us access the many data sets required for the analyses presented here. They include General Liquor Distribution Branch of the BC Ministry of Public Safety and Solicitor, the Nova Scotia Liquor Commission

(NSLC) and the Liquor Control Board of Ontario (LCBO) for access to detailed weekly alcohol sales data. The Public Health Agency of Canada's Stringency and Disease Outcomes Team within the PHAC COVID-19 Modelling Group for compilation and access to data on the stringency of public health measures introduced in Canada during COVID-19. We also acknowledge gratefully funding received from the Centre for Addiction and Mental Health as a subagreement for a Canadian Institutes for Health Research (Institute of Population and Public Health grant 423809, Principal Investigator: K. Shield) and from the Public Health Agency of Canada.

DECLARATION OF INTERESTS

None.

AUTHOR CONTRIBUTIONS

Tim Stockwell: Conceptualization; data curation; funding acquisition; investigation; methodology; project administration; resources; supervision. **Jinhui Zhao:** Data curation; formal analysis; methodology; validation. **Fariha Alam:** Data curation; methodology; project administration. **Samuel Churchill:** Data curation; formal analysis; methodology. **Yipu Shi:** Conceptualization; funding acquisition; investigation; methodology; resources; supervision. **Timothy Naimi:** Conceptualization; funding acquisition; investigation; methodology; project administration; resources.

ORCID

Tim Stockwell https://orcid.org/0000-0002-5696-6803
Jinhui Zhao https://orcid.org/0000-0003-2166-5370

REFERENCES

1. Statistics Canada. Canadian Tobacco, Alcohol and Drugs Survey (CTADS), Annual 2017—User Guide. Ottawa, Canada: Statistics Canada; 2017.
2. Canadian Substance Use Costs and Harms Scientific Working Group. Estimating Canadian substance use costs and harms. Ottawa, Canada: Canadian Institute for Substance Use Research and the Canadian Centre on Substance Use and Addiction; 2018.
3. Government of Canada. Coronavirus Disease (COVID-19): Outbreak Update. 2020. Available at: https://www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection.html?topic=tilelink (Accessed 25 September 2020).
4. World Health Organization. Coronavirus Disease (COVID-19). 2021. Available at: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/coronavirus-disease-covid-19 (Accessed 25 September 2020).
5. Stockwell T, Andreasson S, Cherpitel C, Chikritzhs T, Dangardt F, Holder H, et al. The burden of alcohol on health care during COVID-19. Drug Alcohol Rev. 2021;40:3–7.
6. Gurrieri L, Fairbairn CE, Sayette MA, Bosch N. Alcohol narrows physical distance between strangers. Proc Natl Acad Sci USA. 2021;118: e2101937118.
7. Cucinotta D, Vanelli M. WHO declares COVID-19 a pandemic. Acta Biomed. 2020;91:157–60.
8. Opp S, Mosier S. Liquor, marijuana, and guns: essential services or political tools during the Covid-19 pandemic? Policy Des Pract. 2020;3:297–311.
9. Canadian Broadcasting Corporation. N.W.T. government will not close liquor stores, despite pushback from community leaders. 2020. Available at: https://www.cbc.ca/news/canada/north/liquor-sales-covid19-nwt-government-statement-1.5527649 (Accessed 9 April 2020).
10. Canadian Broadcasting Corporation. Do alcohol and COVID-19 isolation mix? Some health experts don't think so. Available at: https://www.cbc.ca/news/health/covid-19-alcohol-sales-physical-distancing-1.5520433 (Accessed 7 April 2020).
11. Manthey J, Kilian C, Carr S, Bartak M, Bloomfield K, Braddick F, et al. Use of alcohol, tobacco, cannabis, and other substances during the first wave of the SARS-CoV-2 pandemic in Europe: A survey on 36,000 European substance users. Subst Abuse Treat Prev Policy. 2021;16:1–11.
12. Statistics Canada. Self-perceived mental health during the COVID-19 pandemic and cannabis, alcohol and tobacco use. 2020. Available at: https://www150.statcan.gc.ca/n1/daily-quotidien/200507/dq200507g-eng.htm (Accessed 25 March 2021).
13. Vandenberg B, Livingston M, O'Brien K. When the pubs closed: beer consumption before and after the first and second waves of COVID-19 in Australia. Addiction. 2021;116:1709–15.
14. Medina-Mora ME, Cordero-Oropeza M, Rafful C, Real T, Villatoro-Velazquez JA. COVID-19 and alcohol in Mexico: a serious health crisis, strong actions on alcohol in response—commentary on Stockwell *et al*. Drug Alcohol Rev. 2021;40:13–6.
15. Mahadevan J, Shukla L, Benegal V. Alcohol controls in the aftermath of the COVID-19 pandemic in India: commentary on Stockwell *et al*. 2020. Drug Alcohol Rev. 2021;40:10–2.
16. Parry CDH. A timely piece that resonates with the south African experience: commentary on Stockwell *et al*. Drug Alcohol Rev. 2021; 40:8–9.
17. Ministry of Public Safety and Solicitor General of British Columbia. Sale, delivery of packaged liquor now permanent Victoria, BC: Ministry of Public Safety and Solicitor General; 2021. Available at: https://news.gov.bc.ca/releases/2021PSSG0020-000460 (Accessed 28 June 2022).
18. Attorney General of Ontario. Ontario Permanently Allowing Alcohol with Food Takeout and Delivery Toronto, ON: Attorney General of Ontario. Available at: https://news.ontario.ca/en/release/59542/ontario-permanently-allowing-alcohol-with-food-takeout-and-delivery (Accessed 28 June 2022).
19. Ferguson R. LCBO launches online sales, home delivery. Toronto Star Toronto: Toronto Star; 2016. Available at: https://www.thestar.com/news/queenspark/2016/07/26/lcbo-launches-online-sales-home-delivery.html (Accessed 28 June 2022).
20. Alcohol and Gaming Commision of Ontario. Changes to minimum price for spirits ordered with food for takeout and delivery Toronto: Alcohol and Gaming Commision of Ontario (AGCO); 2020. Available at: https://www.agco.ca/blog/alcohol/may-2020/changes-minimum-price-spirits-ordered-food-takeout-and-delivery (Accessed 29 June 2022).
21. Chodkiewicz J, Talarowska M, Miniszewska J, Nawrocka N, Bilinski P. Alcohol consumption reported during the COVID-19 pandemic: the initial stage. Int J Environ Res Public Health. 2020;17:1–11.
22. McDowall D, McCleary R, Meidinger EE, Hay JRA. Interrupted Time Series Analysis. Beverly Hills/London, UK: Sage Publications; 1980.
23. Box GEP, Jenkins GM. Time Series Analysis: Forecasting and Control. San Francisco: Holden-Day; 1976.
24. Lagarde M. How to do (or not to do)… assessing the impact of a policy change with routine longitudinal data. Health Policy Plan. 2012; 27:76–83.
25. Laird NM, Ware JH. Random-effects models for longitudinal data. Biometrics. 1982;38:963–74.
26. Little RC, Stroup WW, Freund RJ. SAS for Linear Models 4th ed. Cary, NC: SAS Institute Inc.; 2002.
27. Raffalovich LE, Chung R. Models for pooled time-series cross-section data. Int J Confl Violence. 2014;8:209–21.

28. Statistics Canada. Table 17-10-0057-01 Projected population, by projection scenario, age and sex, as of July 1 (x 1,000). Available at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710005701; 2021. (Accessed 25 March 2021).
29. Stockwell T, Chikritzhs T. International Guide for Monitoring Alcohol Consumption and Related Harm Geneva, Switzerland: World Health Organization; 2000. Available at: http://apps.who.int/iris/bitstream/10665/66529/1/WHO_MSD_MSB_00.4.pdf (Accessed 13 December 2016).
30. Brewers Retail Inc. 2019 Annual Financial Statements Toronto, ON: Brewers Retail Inc; 2019. Available at: https://www.thebeerstore.ca/about-us/operational-report/ (Accessed 14 January 2022).
31. Government of Canada. 2021. Available at: https://health-infobase.canada.ca/covid-19/ (Accessed 29 April 2021).
32. McNeil DR, Trussell TJ, Turner JC. Spline interpolation of demographic data. Demography. 1977;14:245–52.
33. DeBoor C. A Practical Guide to Splines. New York, NY: Springer-Verlag; 1981.
34. Public Health Agency of Canada. The Public Health Agency's (PHAC) COVID-19 Stringency Index. 2021. Available at: https://data.phac-aspc.gc.ca/views/P_Tdraftv4/PTLineGraph/bavery/db6bc3a2-3bb6-408b-a655-e134524cd078?:display_count=n&:showVizHome=n&:origin=viz_share_link (Accessed 29 April 2021).
35. Hale T, Angrist N, Goldszmidt R, Kira B, Petherick A, Phillips T, et al. A global panel database of pandemic policies (Oxford COVID-19 government response tracker). Nat Hum Behav. 2021;5:529–38.
36. Anderson D, Sweeney D, Williams T, Camm J, Cochran J. Statistics for Business and Economics 13th ed. Minneapolis/St Paul: Cengage Learning; 2014.
37. Piser LM. A method of calculating weekly seasonal indexes. J Am Stat Assoc. 1932;27:307–9.
38. Zhao JH, Stockwell T, Vallance K, Hobin E. The effects of alcohol warning labels on population alcohol consumption: an interrupted time series analysis of alcohol sales in Yukon, Canada. J Stud Alcohol Drugs. 2020;81:225–37.
39. Zhao JH, Stockwell T. The impacts of minimum alcohol pricing on alcohol attributable morbidity in regions of British Colombia, Canada with low, medium and high mean family income. Addiction. 2017; 112:1942–51.
40. Feng C, Wang H, Lu N, Chen T, He H, Lu Y, et al. Log-transformation and its implications for data analysis. Shanghai Arch Psychiatry. 2014;26:105–9.
41. Leigh M, William C. Introduction to data analysis. In: Metcalf L, Casey W, editorsCybersecurity and Applied Mathematics Wilmington, DE: Elsevier Inc.; 2016:43–65.
42. Durbin J, Watson GS. Testing for serial correlation in least squares regression. II. Biometrika. 1951;38:159–78.
43. SAS Institute Inc. SAS/ETS® 13.2 User's Guide. Cary, NC: SAS Institute Inc.; 2014.
44. White H. A Heteroskedasticity-consistent covariance-matrix estimator and a direct test for heteroskedasticity. Econometrica. 1980;48: 817–38.
45. Allison PD. Fixed Effects Regression Methods for Longitudinal Data Using SAS. Cary, NC: SAS Institute; 2005.
46. Woodward M. Epidemiology Study Design and Data Analysis. New York, NY: Chapman & Hall/CRC; 2000.
47. SAS Institute. SAS/STAT 9.4 User's Guide Cary, NC: SAS Institute Inc.; 2016.
48. WorldAtlas. The Most Visited Canadian Provinces and Territories. 2019. Available at: https://www.worldatlas.com/articles/the-most-visited-canadian-provinces-and-territories.html (accessed 8 December 2021).
49. Giesbrecht N, Wettlaufer A, Stockwell T, Vallance K, Chow C, April N, et al. Alcohol retail privatisation in Canadian provinces between 2012 and 2017. Is decision making oriented to harm reduction? Drug Alcohol Rev. 2021;40:459–67.
50. Burdorf A, Porru F, Rugulies R. The COVID-19 (coronavirus) pandemic: consequences for occupational health. Scand J Work Environ Health. 2020;46:229–30.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Stockwell T, Zhao J, Alam F, Churchill S, Shi Y, Naimi T. Alcohol sales in Canadian liquor outlets as a predictor of subsequent COVID-19 infection rates: a time-series analysis. Addiction. 2022. https://doi.org/10.1111/add.16011