

Evaluating the impact of minimum unit pricing (MUP) on off-trade alcohol sales in Scotland: an interrupted time–series study

Mark Robinson^{1,2} , Daniel Mackay² , Lucie Giles³, Jim Lewsey² , Elizabeth Richardson³ & Clare Beeston³

Institute for Social Science Research, University of Queensland, Indooroopilly, Queensland, Australia,¹ Institute of Health and Wellbeing, University of Glasgow, Glasgow, UK² and Public Health Scotland, Glasgow, UK³

Background and Aims On 1 May 2018, Scotland became the first country in the world to introduce minimum unit pricing (MUP), a strength-based floor price below which alcohol cannot be sold, across all alcoholic beverages. The legislation contains a sunset clause meaning a comprehensive mixed-methods evaluation of its impact across a range of outcomes will inform whether it will continue beyond its sixth year. In this study, we assessed the impact of MUP on off-trade alcohol sales (as a proxy for consumption) after its first year. **Design, Setting and Participants** Controlled interrupted time–series regression was used to assess the impact of MUP on alcohol sales among off-trade retailers in Scotland in the year after it was introduced, with England and Wales (EW) being the control group. In adjusted analyses, we included household disposable income, on-trade alcohol sales and substitution between beverage categories as covariates. **Measurements** Weekly data on the volume of pure alcohol sold by off-trade retailers in Scotland and EW between January 2013 and May 2019, expressed as litres of pure alcohol per adult. **Findings** The introduction of MUP in Scotland was associated with a 3.5% [95% confidence interval (CI) = 2.2–4.9%] reduction in off-trade alcohol sales per adult after adjustment for the best available geographical control, disposable income and substitution. In unadjusted analysis, the introduction of MUP was associated with a 2.0% (95% CI = 0.4–3.6%) reduction in off-trade alcohol sales per adult in Scotland. In EW, there was a 2.4% (95% CI = 0.8–4.0%) increase during the same time-period. The reduction in off-trade alcohol sales in Scotland was driven by reduced sales of spirits, cider and perry beverage categories. **Conclusion** The implementation of minimum unit pricing for alcohol in Scotland in 2018 appears to have been associated with a reduction in off-trade alcohol sales after its first year.

Keywords Alcohol, consumption, interrupted time–series, minimum unit pricing, policy analysis, sales.

Correspondence to: Mark Robinson, Institute for Social Science Research The University of Queensland Long Pocket Precinct, 80 Meiers Road Indooroopilly Qld 4068 Australia. E-mail: mark.robinson@uq.edu.au

Submitted 17 June 2020; initial review completed 2 September 2020; final version accepted 4 March 2021

INTRODUCTION

Alcohol is a major contributor to the global burden of disease, particularly in the European region [1]. In Scotland, the rate of deaths related to liver cirrhosis, an indicator of alcohol harm, is among the highest in western and central Europe [2]. Despite falling from a peak in 2003, rates of alcohol-specific deaths remain twice as high as those seen in England and Wales (EW) [3]. Recent estimates using Scotland-level data suggest that alcohol was a causal factor in more than 3700 deaths and 41 000 hospital admissions, and contributed to 8% of the overall disease burden [4]. This is driven by high levels of population alcohol consumption relative to neighbouring countries [4].

In recognition of the harm alcohol was causing, the Scottish Government introduced a comprehensive package of measures through its 2009 Framework for Action [5]. The strategy contained a range of policy and legislative actions which, collectively, aimed to reduce population levels of alcohol consumption and, in turn, associated levels of health and social harms. This included the Alcohol (Minimum Pricing) (Scotland) Act (hereafter ‘MUP Act’), which was passed in June 2012 [6]. Following a lengthy legal challenge, which ended after the judgement of the Supreme Court in December 2017 [7], the Scottish Government implemented MUP on 1 May 2018, setting a minimum price of 50 pence per unit (ppu) of alcohol (a unit of alcohol is equivalent to 10 ml or 8 g of pure

alcohol; 50 ppu is therefore roughly converted to €0.65 per 10 g of pure alcohol or \$1.14 per US standard drink), below which alcohol cannot be sold in licensed premises in Scotland. A feature of the MUP Act is the inclusion of a sunset clause meaning that the legislation will cease to exist beyond its 6th year unless the Scottish Parliament vote for it to continue. This decision will be informed by a comprehensive, mixed-methods evaluation of the impact of MUP across a broad range of outcomes being led by Public Health Scotland [7].

There is strong and consistent evidence to show that increasing the price of alcohol, thereby reducing its affordability, is an effective approach in reducing population levels of alcohol consumption and related harms [8]. In Canada, for example, a form of minimum pricing applies throughout all 10 provinces, although there is variation in the extent and frequency to which different drink types and outlets are affected. Evaluation studies have shown consistently that as minimum prices for alcohol increase there is an associated decrease in population consumption, hospital admissions and deaths [9–12]. In October 2018, the Northern Territory in Australia, like Scotland, introduced MUP across all drink categories. A preliminary assessment of the policy's impact after 12 months showed that total wholesale alcohol supply per capita declined, although this was based on only four quarterly post-intervention data points [13]. The decline was driven by cask wine, which was the beverage category sold at the cheapest prices before the legislation was introduced.

A recent study by O'Donnell *et al.* [14] assessed the impact of MUP on self-reported alcohol purchases in Scotland during the 8-month period after implementation using household consumer panel data. Using interrupted time-series analysis with data for England as a geographical control, the study showed that the introduction of MUP was associated with a net reduction (i.e. Scotland minus EW) in alcohol purchases of 7.6% (9.5 g per adult per household per week). A net reduction in alcohol purchases was observed across all main beverage categories: beer, spirits, cider and wine. In addition, consistent with the estimated impacts from prior modelling studies [15], subgroup analysis showed that the net reduction in alcohol purchases in Scotland was driven by households purchasing the greatest volume of alcohol.

The aim of this study is to examine the impact of the MUP (50 ppu) in Scotland on off-trade alcohol sales (i.e. alcohol sold for consumption off the premises, such as supermarkets and convenience stores) for a full 12-month period post-implementation. An appropriate control was provided by neighbouring countries (EW) to the intervention country (Scotland). We use weekly alcohol sales data as a proxy for off-trade population consumption, which is not prone to self-reporting bias, and is considered an

objective and reliable approach for monitoring and evaluation purposes [16].

METHODS

The methods for this study were guided by a pre-published protocol [17].

Design

We used controlled interrupted time-series analytical methods to assess whether the introduction of MUP was associated with a change in off-trade alcohol sales. We assessed the impact of the legislation on total off-trade alcohol sales per adult (our primary outcome) and on off-trade sales per adult of specific beverage categories, with corresponding data for EW used as a geographical control group. We used off-trade sales as our primary outcome measure because the MUP legislation was not expected to affect the on-trade where the average price per alcohol unit sold was £1.80 in 2017, compared with £0.54 in the off-trade [3]. Statistical models accounted for underlying seasonal and secular trends. Adjustments were made to account for potential substitution between beverage categories, changes in on-trade (e.g. pubs, clubs and restaurants) alcohol sales, as well as changes in disposable income. A range of sensitivity analyses were performed to test the robustness of our main findings to changes in the analytical approach.

Data

Estimates of weekly off-trade alcohol sales were obtained from market research company Nielsen for the period January 2013–May 2019. Data were obtained for Scotland, EW (combined), North East (NE) England and North West (NW) England. Nielsen estimates off-trade alcohol sales in Great Britain using electronic sales records from large retailers (retailers with 10 or more retail shops operating under common ownership) and a weighted stratified random sample of smaller 'impulse' retailers (retailers in which the consumer mainly uses the store for impulse or top-up purchases, i.e. not the main grocery shop). We have previously provided a detailed description of the methods used by Nielsen to produce alcohol retail sales estimates [18].

The volume of alcohol sold (litres) was provided among eight alcoholic beverage categories: spirits, wine, beer, cider, ready to drink beverages (RTDs), perry (an alcoholic beverage similar to cider but made of fermented pear juice) and fortified wine. The volume of each beverage category sold was converted into pure alcohol volume using a category-specific percentage alcohol by volume (ABV) provided by the data suppliers. The ABV used was based on the

typical strength of products sold within subtypes of the category, except for wine, where the same standard ABV was applied across all products due to the diversity of the wine market.

Alcohol sales by discount retailers, Aldi and Lidl, are not included in the Nielsen off-trade alcohol sales estimates. We adjust for their exclusion in sensitivity analysis using alcohol volume market share estimates for calendar years 2013–19 provided by Kantar Worldpanel. Kantar Worldpanel data are collected by a panel of households (participants aged ≥ 18 years) who record their grocery purchases, including alcohol, using a barcode reader. Data are only collected on purchases brought into the home and include details such as quantity, price and the store of purchase. Linear interpolation between the annualized estimates provided was used to calculate weekly alcohol market share estimates for Aldi and Lidl, based on volume sales, by beverage category. Further information, including a plot showing annualized Aldi and Lidl alcohol market share estimates in Scotland and EW between 2011 and 2019, is provided in the Supporting information.

Estimates of 4-weekly on-trade alcohol sales data (litres of pure alcohol) were obtained from market research company, CGA Strategy, whose estimates are based on a combination of delivery, sales and survey data from a stratified sample of on-trade retailers [18]. Data were obtained for the same drink categories and geographies as noted for the off-trade.

Per-adult off-trade and on-trade alcohol sales were calculated by dividing pure alcohol volumes (litres of pure alcohol) by the total population aged ≥ 16 years. Mid-year population estimates and projections for Scotland were obtained from National Records of Scotland [19] and for EW from the Office for National Statistics [20]. The NE and NW England regions used in this study were defined by the data providers based on postcode sectors and are not coterminous with the official Government Office Regions. Mid-year population estimates for these areas were therefore based on the aggregation of mid-year population estimates for Lower Super Output Areas within each postcode sector within each region. Weekly and 4-weekly population estimates were interpolated linearly from the mid-year estimates.

Quarterly gross disposable household income data were obtained for Scotland [21] and the United Kingdom [22]. As data for EW were not available separately, a proxy measure was created by subtracting total gross disposable income in Scotland from total gross disposable income in the United Kingdom. Income data were expressed per adult aged ≥ 16 years using quarterly population estimates interpolated linearly from mid-year population estimates for Scotland and EW (including Northern Ireland to match income data).

Descriptive analysis

In descriptive analysis, we calculated the percentage change in per-adult off-trade alcohol sales when aggregated across the 52-week period before and after MUP was introduced, overall and by beverage category.

Statistical methods

We used controlled interrupted time-series regression with seasonal autoregressive integrated moving average (SARIMA) errors as our main statistical method to assess the impact of MUP on off-trade alcohol sales in Scotland. SARIMA is a particularly powerful approach when analysing aggregated data with a relatively large number of data points, as it enables robust control of autocorrelation, as well as secular and seasonal trends in the data series (the latter being particularly important given the seasonality in alcohol sales) [23].

Our analytical strategy was in line with both the guidance produced by Beard *et al.* [23] and our previous approach when evaluating the impact of the Alcohol, etc. (Scotland) Act in Scotland in 2010 [24]. We first modelled the alcohol sales data time-series to obtain an adequate preliminary model. We then modelled and tested the effect of the intervention with and without adjusting for covariates.

We assessed whether the outcome measures follow a normal distribution using kernel density plots. Prior to modelling we log-transformed the data to stabilize the variance and to reduce the influence of outliers. Candidate models were investigated using autocorrelation and partial autocorrelation plots of the data, with the most appropriate and parsimonious models selected using the Akaike information criterion (AIC) and Bayesian information criteria (BIC) statistics. Lagged effects of MUP were not explored in light of findings from other studies in the MUP evaluation portfolio which have shown that the legislation has been complied with, implemented effectively and had an immediate effect on alcohol purchases [14,25]. Similarly, our preliminary analysis of data on the average sales price of off-trade alcohol did not suggest that there was an anticipatory effect prior to MUP being introduced in Scotland compared with EW [26].

We estimated the magnitude and uncertainty of the effect of MUP implementation on off-trade alcohol sales by including a binary explanatory variable in our SARIMA models, with the value of zero for the time before MUP is introduced (January 2013–April 2018) and the value of one after the introduction of MUP (May 2018–April 2019). Models were all fitted assuming a change in level. This was based on a comparison of AIC and BIC statistics of separate models testing for either: a change in level only; a change in trend only; a change in level and trend.

All SARIMA models in our study took the form:

$$\text{ARIMA}(p, d, q) \times \text{SARIMA}(P, D, Q, S),$$

where p = maximum autoregressive lag, d = differencing, q = maximum moving average lag, P = maximum seasonal autoregressive lag, D = seasonal differencing and Q = maximum seasonal moving average lag, S = seasonal frequency.

Further details on model specification are provided in the Supporting information.

In line with Lopez-Bernal *et al.*'s guidance [27], we used a two-step approach to incorporating our control group data. First, we fitted separate models to off-trade alcohol sales data in Scotland and EW. Second, we entered the EW time-series data as a covariate in the SARIMA models for Scotland to produce a 'controlled' model. Models were fitted to the off-trade alcohol sales data series with and without adjustment for covariates: sales of other alcoholic beverage categories (in models of specific beverage categories); on-trade alcohol sales (Scotland only); and disposable household income.

In our Results section, we present the estimated impact of MUP from our primary analyses based on:

1. Separate unadjusted, uncontrolled models for Scotland and EW.
2. Unadjusted, controlled models for Scotland (in which the EW series is incorporated as a covariate).
3. Adjusted, controlled models for Scotland (as above but also including adjustment for the other covariates).

Presenting results from uncontrolled and controlled analyses, as well as from unadjusted and adjusted analyses, is consistent with reporting guidelines for this type of study [27,28].

For all models, standard diagnostic tests were performed to ensure that the residuals of the fitted models were not significantly different from those expected from white noise or a random series [29]. These are presented in the Supporting information for the adjusted controlled models in Scotland, by beverage category. To assess the goodness-of-fit of our models we calculated *R*-squared using the standard method ($R\text{-squared} = 1 - (\text{SSR}/\text{SST})$, where SSR is the sum of squared residuals from the fitted model and SST is the total sum of squares) [30].

Sensitivity analysis

We performed extensive additional analyses to test the robustness of our results, including: using the net difference between Scotland and EW as the outcome; applying uplift factors to the sales data to account for Aldi and Lidl; repeating our analyses using NW and NE England as controls; applying our analytical approach to overall sales (i.e. on- and

off-trade sales combined); employing an alternative time-series analytical method [unobserved components model (UCM)]; assessing the impact of MUP on 4-weekly on-trade sales in Scotland and EW; and testing whether MUP had an impact on the variability in weekly off-trade sales by modelling the residuals from the main model. Further detail is provided in the Supporting information.

Changes to our published protocol

Our analytical approach was consistent with the pre-specified protocol published in our statistical analysis plan [17]. However, we did not carry out all analyses specified, including: detailed analyses of overall alcohol sales (i.e. both on- and off-trade combined) as the primary outcome; analyses expressing alcohol sales per adult drinker instead of per adult (i.e. excluding non-drinkers from the denominator); falsification tests with alternative legislation dates; or tests for structural breaks as part of our sensitivity analyses. The reasons for this are provided in the Supporting information.

Software

MATLAB[®] (version 9.7 update 1) was used for all SARIMA modelling and Python version 3.7 for the UCM analysis (using the UCM procedure in the 'statsmodels 0.10.2' package).

RESULTS

Descriptive analysis

Figure 1 plots the trend in the volume of off-trade alcohol sales in Scotland and EW between January 2013 and May 2019. There are clear seasonal trends in off-trade alcohol sales, with large spikes in sales observed during the period covering Christmas and New Year's Eve; these trends are very similar in EW and for individual beverage categories (Supporting information, Figs S1–S7). Before MUP implementation, off-trade alcohol sales in Scotland were consistently higher than in EW. However, during the year after MUP was introduced, the difference in weekly off-trade alcohol sales reduced compared with previous years; in 47 of 52 weeks in the post-MUP year, the difference in off-trade alcohol sales between Scotland and EW was lower than in the corresponding week in the pre-MUP year.

Comparing the percentage change in off-trade alcohol sales when aggregated across the 52-week period before and after MUP was introduced shows that off-trade sales in Scotland fell by 2.1%, from 6.74 to 6.60 litres per adult, compared with the previous year (Table 1). In EW, off-trade sales increased by 2.2% during the same time-period. Table 1 shows clear differences by beverage category. In

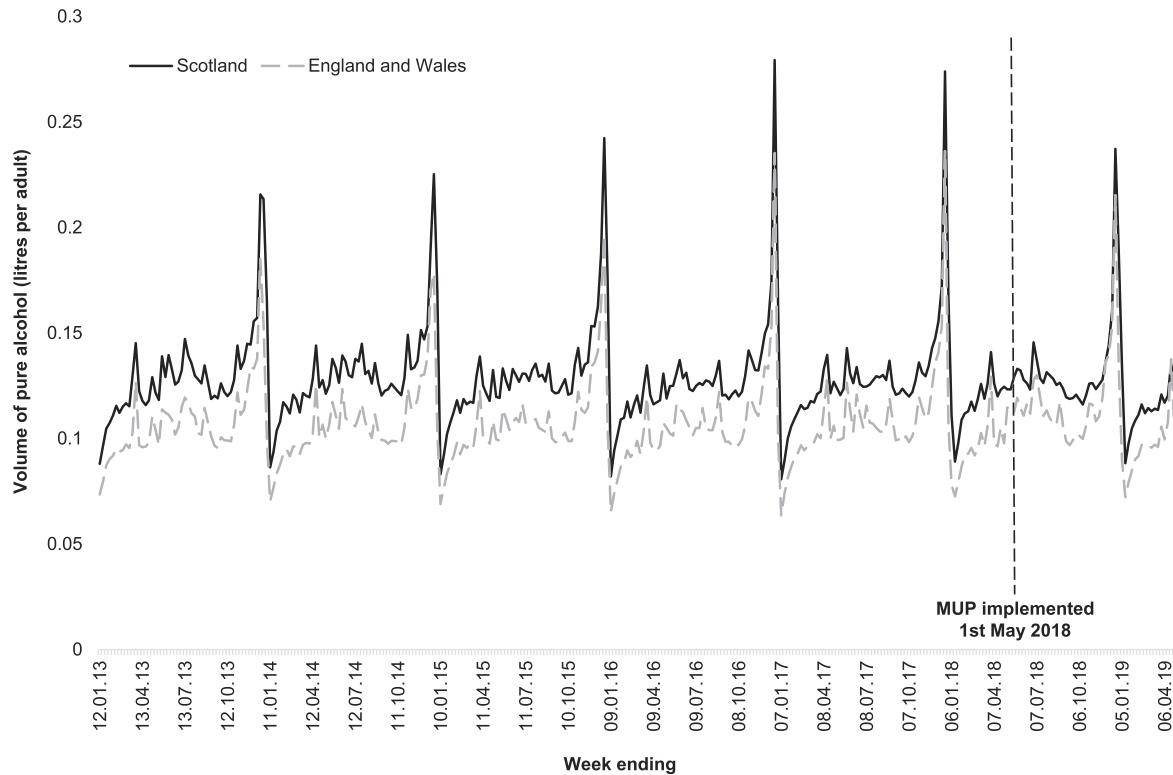


Figure 1 Weekly off-trade alcohol sales (litres of pure alcohol per adult), Scotland and England and Wales, January 2013–May 2019. Off-trade sales data were obtained from Nielsen and exclude sales by Aldi and Lidl

Table 1 Market share and percentage change in the year before and after MUP in annualized volume of pure alcohol sold per adult in the off-trade, Scotland and England and Wales.

	Off-trade volume sales (litres pure alcohol): pre-MUP year	Off-trade market share (%): post-MUP year	Change from previous annual period (%)	
			Pre-MUP year	Post-MUP year
Scotland				
Spirits	2.2	32.5	0.8	-2.7
Wine	2.1	31.3	-0.5	-2.7
Beer	1.6	24.1	-0.1	1.2
Cider	0.5	6.4	3.5	-18.8
Fortified wine	0.2	4.0	12.7	24.5
RTDs	0.1	1.2	15.2	20.0
Perry	0.0	0.4	-4.2	-41.4
All	6.7	100	0.8	-2.1
England and Wales				
Spirits	1.5	26.4	3.9	4.5
Wine	2.0	33.8	-0.2	-3.8
Beer	1.5	28.5	-0.1	6.5
Cider	0.4	8.0	0.5	5.7
Fortified wine	0.1	1.4	-9.4	-3.5
RTDs	0.0	0.9	3.6	19.1
Perry	0.0	0.8	-0.7	1.6
All	5.6	100	0.6	2.2

MUP = minimum unit price; RTDs = ready-to-drink beverages.

Scotland, off-trade sales of all beverage categories reduced after MUP, with the exception of RTDs and fortified wine. In EW, only off-trade sales of wine and fortified wine decreased during the same period.

Interrupted time series

To ease visual interpretation, we present two separate figures for the following groups of beverage categories: total off-trade, wine, spirits and beer (Fig. 2a); and cider, perry, fortified wine and RTDs (Fig. 2b). Full results from all statistical analyses are tabulated in the Supporting information.

In unadjusted, uncontrolled analysis, the introduction of MUP was associated with a 2.0% [95% confidence interval (CI) = 0.4–3.6%, $P = 0.014$] reduction in off-trade sales per adult in Scotland (Fig. 2a). In EW, there was a 2.4% (95% CI = 0.8–4.0%, $P = 0.004$) increase during the same time-period. In the unadjusted, controlled model, MUP was associated with a 3.3% (95% CI = 2.1–4.4%, $P < 0.001$) reduction in total off-trade sales in Scotland. A similar estimate was produced when the controlled model was adjusted for disposable income and substitution (–3.5%, 95% CI = –4.9 to –2.2%, $P < 0.001$).

In unadjusted, controlled analysis by beverage category, MUP was associated with reductions in off-trade sales of spirits, cider and perry in Scotland in the year after MUP (Fig. 2a,b). There was a null association between MUP and off-trade wine sales, while there was a net increase in off-trade sales of RTDs and fortified wine. Adjustment for on-trade sales, income and off-trade sales of other beverage categories did not have a notable impact on these estimates, with the exception of wine, for which the direction of effect became positive (i.e. MUP was associated with a net increase in off-trade wine sales).

Sensitivity analyses

Figure 3 shows that the range of sensitivity analysis we performed generated similar estimates of the effect of MUP on total off-trade sales, as in our main analysis when using data for adjusted models using EW as the control series. Higher reductions in alcohol sales were associated with the introduction of MUP when data for NE and NW England were used as the control series.

In our sensitivity analyses that used all alcohol sales as the outcome series (i.e. off- and on-trade sales combined), results by beverage category were mainly in the same direction to those presented in Fig. 2 (based on an adjusted, controlled model), although there were some differences in the magnitude of the association. An exception to this was wine: in our main analysis we observed a small increase in wine associated with the introduction of MUP, whereas in the model including combined alcohol sales,

the association was negative (Supporting information, Table S12). When we modelled the effect of MUP on 4-weekly on-trade alcohol sales there was a null association for total on-trade sales in Scotland (–0.3%, 95% CI = –1.4 to 0.8%) and EW (0.8%, 95% CI = –0.2 to 1.8%). The direction of the observed association for the main beverage categories was also similar between Scotland and EW (Supporting information, Tables S12 and S13). Results from all sensitivity analysis are provided in the Supporting information.

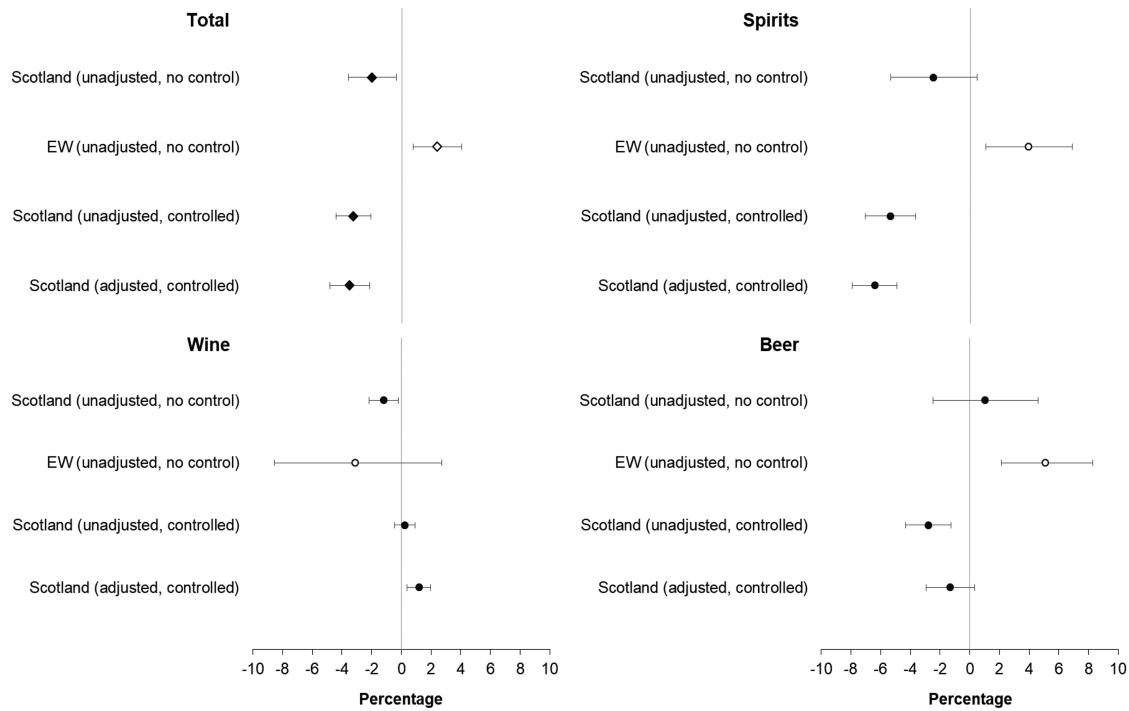
DISCUSSION

Main findings

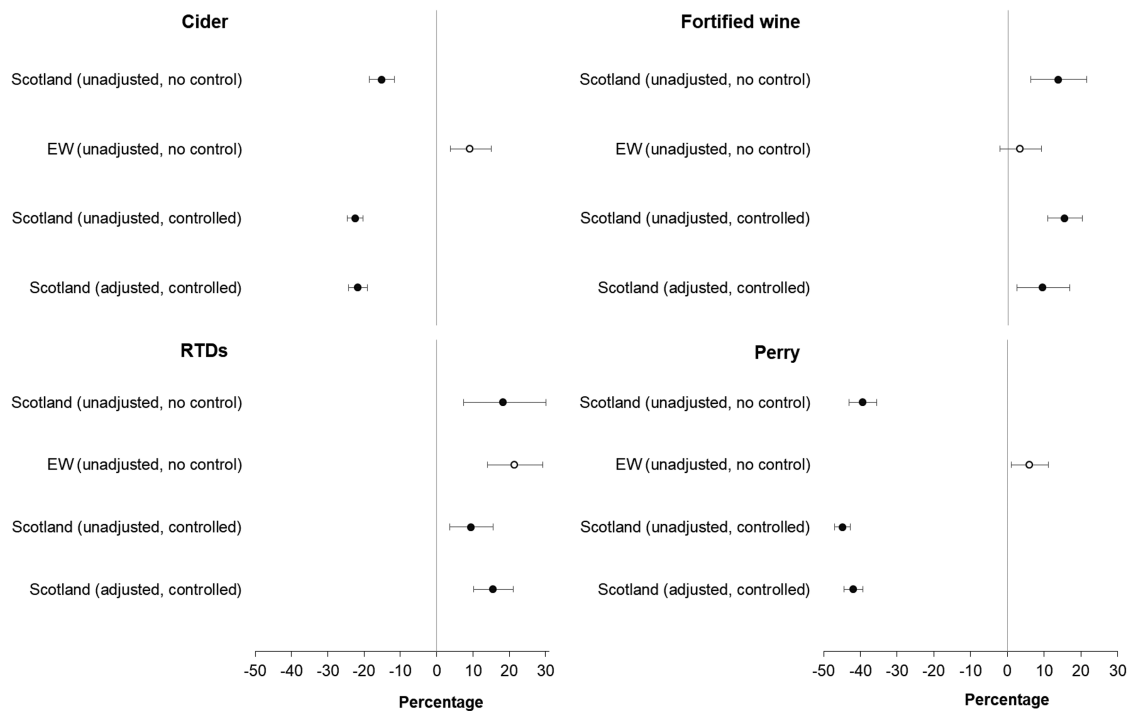
This study provides evidence that the introduction of MUP in Scotland on 1 May 2018 was associated with a 2.0% reduction in off-trade alcohol sales per adult in Scotland in the following 12-month period. In EW, where the legislation does not apply, per-adult alcohol sales increased during the same time-period. Based on a model that adjusted for household income and on-trade sales, and controlled for alcohol sales in EW, our best estimate of the net reduction in per-adult off-trade sales in Scotland was 3.5%. As we accounted for underlying trends in our analyses, as well as other covariates that may explain part of the effect of MUP on off-trade alcohol sales, it is reasonable to conclude that MUP caused the reductions observed.

Strengths

We used alcohol sales data (converted to pure alcohol volumes and expressed per adult) as our proxy for population consumption, which is considered the most objective and reliable approach [16]. Our study design also incorporated data for EW as a geographical control series. By comparing with, and controlling for, the change in off-trade alcohol sales in EW during the 12-month period after MUP was introduced in Scotland, we can be more confident that the observed reduction in Scotland was due to MUP rather than another unmeasured factor. Furthermore, our analytical approach enabled underlying trends in the data series to be taken into account, as well as other important time-varying factors. We found our estimated effects to be robust to substitution between beverage categories and changes in household income, which were entered as covariates in our adjusted statistical models. Finally, we performed a range of sensitivity analyses to test the robustness of our main findings to changes in the model specification and analytical method employed. We observed similar findings across these different approaches, which increases the validity of our findings.



a



b

Figure 2 (a) Change (%) in off-trade alcohol sales in the year after MUP was implemented in Scotland for all alcohol, spirits, wine and beer. EW = England and Wales. ‘Controlled’ models include trends in off-trade alcohol sales in England and Wales as a covariate. ‘Adjusted’ models include trends in household disposable income, on-trade sales and, for analyses of specific beverage categories, off-trade alcohol sales of other beverage categories as covariates. All models are adjusted for underlying seasonal and secular trends. (b) Change (%) in off-trade alcohol sales in the year after MUP was implemented in Scotland for cider, fortified wine, RTDs and perry. ‘Controlled’ models include trends in off-trade alcohol sales in England and Wales as a covariate. ‘Adjusted’ models include trends in household disposable income, on-trade sales and, for analyses of specific beverage categories, off-trade alcohol sales of other beverage categories as covariates. All models are adjusted for underlying seasonal and secular trends. RTDs = ready-to-drink beverages

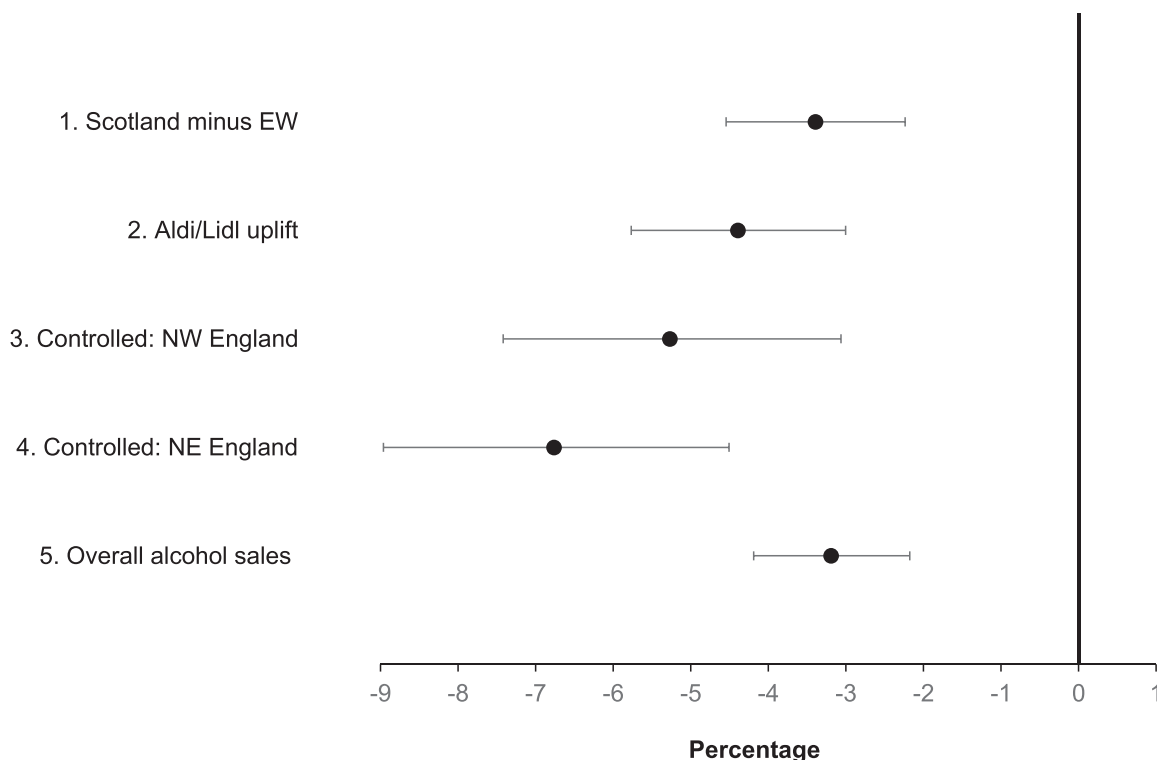


Figure 3 Change (%) in off-trade alcohol sales in the year after MUP was implemented in Scotland estimated from multiple sensitivity analyses. EW = England and Wales; NE = North East England; NW = North West England. Model 1: the outcome series is off-trade alcohol sales in Scotland minus off-trade alcohol sales in EW; model 2: the outcome series is off-trade alcohol sales in Scotland that have been adjusted for the alcohol market share held by Aldi and Lidl (note the control series in EW was also adjusted); model 3: off-trade alcohol sales in NW England are entered as the control series; model 4: off-trade alcohol sales in NE England are entered as the control series; model 5: the outcome series is combined on- and off-trade sales in Scotland (4-weekly). Models 1, 2 and 5 incorporate off-trade alcohol sales in EW as a control. All models include trends in on-trade sales (excluding model 5) and household disposable income as covariates and are adjusted for underlying seasonal and secular trends

Limitations

Important limitations to our study include the fact that alcohol sales data cannot be disaggregated to assess how sales differ across population subgroups. Modelling suggested that consumption among the heaviest drinkers, who typically consume the cheapest alcohol, was likely to be affected most by the introduction of MUP in Scotland, particularly those living in low-income households [15]. Recent findings by O'Donnell *et al.* provided support for this, suggesting that reduced alcohol purchasing in Scotland was driven, as hypothesized, by reductions among households purchasing the highest volumes of alcohol [14]. While it was not possible to assess such differential impacts with the retail sales data we have used, the beverage categories most affected—cider, perry and spirits (a large volume of which were previously sold at low cost) [31]—are those consumed in greater quantities by heavier drinkers and those living in areas with higher levels of socio-economic deprivation [32,33]. Finally, we only included data for a 1-year post-implementation period. It was important to assess the short-term impact of MUP on population consumption; the theory of change for MUP

postulates that the legislation will reduce alcohol-related harms through an immediate reduction in population consumption. Nonetheless, it is important to consider both short- and longer-term effects of new public policy, as any short-term impact may not be sustained. These limitations will be addressed by triangulating results from this study with those generated from others contributing to the multi-component MUP evaluation being led by Public Health Scotland [7]. In addition, we will repeat this study when data for a full 3-year post-MUP period become available, as well as with off-trade sales estimates from another data supplier. We will also examine the impact of the COVID-19 lockdown on alcohol retail sales in Scotland and in EW. Finally, natural experimental studies can be particularly vulnerable to confounding. However, comparison of the estimated effect with our control series, as well as the variation in the size of effect across beverage categories with different pre-MUP prices, provides reassurance that the observed effects were attributable to MUP and not to other unmeasured factors.

It has been suggested that an unintended consequence of MUP in Scotland might be to increase cross-border shopping, i.e. alcohol consumers purchasing lower priced

alcohol in the north of England for consumption in Scotland. It was not possible to directly examine this in our study. However, the increase in per-adult off-trade alcohol sales in the northern English regions was broadly similar to that observed for EW overall. It is therefore highly unlikely that cross-border purchasing could account for the net effect of MUP reported here.

Interpretation

The largest relative net reductions in per-adult off-trade alcohol sales were observed for cider and perry. Smaller net reductions were seen for spirits and beer; however, these account for a greater share of the off-trade market and so likely made an important contribution to the fall in total off-trade sales in Scotland during the year after MUP was introduced. The reductions observed in these beverage categories were partly offset by off-trade sales of fortified wine and RTDs, which both increased in the post-MUP year, but account for a small share of the off-trade alcohol market. Our results are broadly consistent with those of O'Donnell *et al.*, who reported reductions in self-reported alcohol purchase volumes for beer, spirits, cider and wine during the 8-month period after MUP [14]. While we observed reduced off-trade wine sales associated with MUP in an uncontrolled, unadjusted model for Scotland, the association reversed direction in the controlled, adjusted model (this seemed to be primarily due to adjustment for off-trade sales of other beverage categories; *post-hoc* analysis not shown). As well as the data used and time-period analysed, other differences between the methods employed may explain variations in the findings.

The impact of MUP on off-trade alcohol sales in Scotland is most probably explained by the policy's effect on alcohol prices. The beverage categories for which we estimated net reductions in off-trade sales in Scotland were also those that had the highest proportion of their sales at below 50 ppu before MUP was introduced [31]. They were also the beverage categories with the largest increases in average sales price after MUP was implemented [26]. In contrast, wine, fortified wine and RTDs were typically sold at prices above the 50 ppu threshold before MUP was introduced, and off-trade sales of these beverage categories increased in association with MUP. These patterns are consistent with other findings. In the Northern Territory, Australia, a recent report found that the largest decline in wholesale alcohol supply per capita in the year after minimum pricing for alcohol was introduced was for cask wine, which was also the beverage category with the highest price increase [13]. In Canada, a form of minimum pricing applies throughout all 10 provinces, although there is variation in the extent and frequency to which different drink types and outlets are affected. Studies have examined the effect of a 10% increase in the minimum price for alcohol

on alcohol sales. In British Columbia, for example, such an increase was associated with a 3.4% decrease in total alcohol consumption, as measured by sales data [11]. The size of the effect differed among drink types, with impacts upon higher-strength beverages particularly affected. In Saskatchewan, which has the form of minimum pricing most similar to MUP, a 10% increase in minimum prices was associated with an 8.4% decrease in total alcohol sales [10]. Effects were most pronounced in the off-trade, and there was evidence of a shift in sales from higher- to lower-strength products.

CONCLUSION

In conclusion, results from our natural experimental study suggest that MUP has been effective in reducing population off-trade alcohol sales in Scotland during the 1-year period after it was implemented. These results will provide an important contribution to the overall evaluation of MUP effectiveness among a range of health, social and economic outcomes which, in turn, will influence the future of this novel alcohol control policy.

Declaration of interests

None.

Acknowledgements

This study was undertaken as part of the Monitoring and Evaluating Scotland's Alcohol Strategy (MESAS) work programme, which is led by Public Health Scotland. Public Health Scotland and MESAS are funded by Scottish Government. The Memorandum of Understanding between the Scottish Government and Public Health Scotland permits the Scottish Government, as well as an Evaluation Advisory Group, to comment on draft reports and papers; however, the final content of the work submitted and the decision to submit for publication was the sole responsibility of the authors. The authors express thanks to members of the MUP Consumption and Health Harm EAG, who provided guidance on the study design and comments on an earlier version of the paper. We also thank Dr Karl Ferguson (Public Health Scotland) for his support with the interpretation of results. Finally, we thank the peer-reviewers for their insightful and constructive comments.

Author contributions

Mark Robinson: Conceptualization; data curation; formal analysis; methodology; writing-original draft. **Daniel Mackay:** Conceptualization; formal analysis; methodology; writing-review & editing. **Lucie Giles:** Conceptualization; data curation; methodology; writing-review & editing. **James Lewsey:** Conceptualization; formal analysis;

methodology; writing-review & editing. **Elizabeth Richardson:** Data curation. **Clare Beeston:** Conceptualization; funding acquisition; writing-review & editing.

References

- World Health Organization *Global Status Report on Alcohol and Health 2018*. Geneva, Switzerland: World Health Organization; 2018.
- Whyte B., Ajetunmobi T. Still 'The Sick Man of Europe'? *Scottish Mortality in a European context 1950–2010. An Analysis of Comparative Mortality Trends*. Glasgow: Glasgow Centre for Population Health; 2012.
- Giles L., Robinson M. *Monitoring and Evaluating Scotland's Alcohol Strategy: Monitoring Report 2018*. Edinburgh, UK: NHS Health Scotland; 2018.
- Tod E., Grant I., Wyper G., Stockton D., Robinson M., McCartney G., et al. *Hospital admissions, deaths and overall burden of disease attributable to alcohol consumption in Scotland*. Glasgow, UK: NHS Health Scotland/ScotPHO; 2018.
- Scottish Government *Changing Scotland's Relationship with Alcohol: A Framework for Action*. Edinburgh, UK: Scottish Government; 2009.
- Scottish Parliament *Alcohol (Minimum Pricing) (Scotland) Act*. Edinburgh, UK: Scottish Parliament; 2012.
- Beeston C., Robinson M., Giles L., Dickie E., Ford J., McPherson M., et al. Evaluation of minimum unit pricing of alcohol: a mixed method natural experiment in Scotland. *Int J Environ Res Public Health* 2020; **10**: 3394.
- Burton R., Henn C., Lavoie D., O'Connor R., Perkins C., Sweeney K., et al. A rapid evidence review of the effectiveness and cost-effectiveness of alcohol control policies: an English perspective. *Lancet* 2017; **389**: 1558–80.
- Stockwell T., Zhao J., Martin G., Macdonald S., Vallance K., Treno A., et al. Minimum alcohol prices and outlet densities in British Columbia, Canada: estimated impacts on alcohol-attributable hospital admissions. *Am J Public Health* 2013; **103**: 2014–20.
- Stockwell T., Zhao J., Giesbrecht N., Macdonald S., Thomas G., Wettlaufer A. The raising of minimum alcohol prices in Saskatchewan, Canada: impacts on consumption and implications for public health. *Am J Public Health* 2012; **102**: e103–e110.
- Stockwell T., Auld M. C., Zhao J., Martin G. Does minimum pricing reduce alcohol consumption? The experience of a Canadian province. *Addiction* 2012; **107**: 912–20.
- Zhao J., Stockwell T., Martin G., Macdonald S., Vallance K., Treno A., et al. The relationship between minimum alcohol prices, outlet densities and alcohol-attributable deaths in British Columbia, 2002–09. *Addiction* 2013; **108**: 1059–69.
- Coomber K., Miller P., Taylor N., Livingston M., Smith J., Buykx P., et al. *Investigating the introduction of the alcohol minimum unit price in the Northern Territory: Final Report*. Geelong, Australia: Deakin University; 2020.
- O'Donnell A., Anderson P., Jané-Llopis E., Manthey J., Kaner E., Rehm J. Immediate impact of minimum unit pricing on alcohol purchases in Scotland: controlled interrupted time series analysis for 2015–18. *BMJ* 2019; **366**: 15274.
- Angus C., Holmes J., Pryce R., Meier P., Brennan A. *Model-based Appraisal of the Comparative Impact of Minimum Unit Pricing and Taxation Policies in Scotland: An Adaptation of the Sheffield Alcohol Policy Model version 3*. Sheffield, UK: ScHARR, University of Sheffield; 2016.
- World Health Organization *International Guide for Monitoring Alcohol Consumption and Related Harm*. Geneva, Switzerland: World Health Organization; 2000.
- Robinson M., Lewsey J., Mackay D., Giles L., Beeston C. *Evaluating the Impact of Minimum Unit Pricing (MUP) on Sales-based Consumption in Scotland: Statistical Analysis Plan*. Edinburgh, UK: NHS Health Scotland; 2019.
- Thorpe R., Robinson M., McCartney G., Beeston C. *Monitoring and Evaluating Scotland's Alcohol Strategy: A Review of the Validity and Reliability of Alcohol Retail Sales Data for the Purpose of Monitoring and Evaluating Scotland's Alcohol Strategy*. Edinburgh, UK: NHS Health Scotland; 2012.
- National Records of Scotland. Mid-year population estimates. Available at: <https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/population/population-estimates/mid-year-population-estimates> (accessed 9 March 2020).
- Office for National Statistics. Population estimates. Available at: <https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates> (accessed 9 March 2020).
- National Records of Scotland. GDP Quarterly National Accounts, 2019 Quarter 2: Detailed Supplementary Tables (Table 14). 2019. Available at: <https://www2.gov.scot/Topics/Statistics/Browse/Economy/QNA2019Q2> (accessed 9 March 2020).
- Office for National Statistics. Households (S.14): Disposable income, gross (B.6g): UsesResources: Current price: £m: NSA. 2019. Available at: <https://www.ons.gov.uk/economy/grossdomesticproductgdp/timeseries/habn/ukea> (accessed 9 March 2020).
- Beard E., Marsden J., Brown J., Tombor I., Stapleton J., Michie S., et al. Understanding and using time-series analyses in addiction research. *Addiction* 2019; **114**: 1866–84.
- Robinson M., Geue C., Lewsey J., Mackay D., McCartney G., Curnock E., et al. Evaluating the impact of the alcohol act on off-trade alcohol sales: a natural experiment in Scotland. *Addiction* 2014; **109**: 2035–43.
- Dickie E., Mellor R., Myers F., Beeston C. *Minimum Unit Pricing (MUP) Evaluation: Compliance (licensing) study*. Edinburgh, UK: NHS Health Scotland; 2019.
- Giles L., Robinson M., Beeston C. *Minimum Unit Pricing (MUP) Evaluation. Sales-based consumption: a descriptive analysis of one year post-MUP off-trade alcohol sales data*. Edinburgh, UK: NHS Health Scotland; 2020.
- Lopez Bernal J., Cummins S., Gasparrini A. The use of controls in interrupted time series studies of public health interventions. *Int J Epidemiol* 2018; **47**: 2082–93.
- Vandenbroucke J. P., von Elm E., Altman D. G., Gotzsche P. C., Mulrow C. D., Pocock S. J., et al. Strengthening the reporting of observational studies in epidemiology (STROBE): explanation and elaboration. *PLOS Med* 2007; **4**: e297.
- Ljung G. M., Box G. E. P. On a measure of lack of fit in time series models. *Biometrika* 1978; **65**: 297–303.
- Wooldridge J. *Introductory Econometrics: A Modern Approach, 7th edn*. Andover, UK: Cengage Learning; 2020.
- Giles L., Robinson M. *Monitoring and Evaluating Scotland's Alcohol Strategy: Monitoring Report 2019*. Edinburgh, UK: NHS Health Scotland; 2019.
- Meier P. S., Holmes J., Angus C., Ally A. K., Meng Y., Brennan A. Estimated effects of different alcohol taxation and price

policies on health inequalities: a mathematical modelling study. *PLOS Med* 2016; **13**: e1001963.

33. Black H., Gill J., Chick J. The price of a drink: levels of consumption and price paid per unit of alcohol by Edinburgh's ill drinkers with a comparison to wider alcohol sales in Scotland. *Addiction* 2011; **106**: 729–36.

Supporting Information

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

Figure S1 Weekly off-trade spirits consumption (litres of pure alcohol per adult), Scotland and England and Wales, January 2013 to May 2019.

Figure S2 Weekly off-trade wine consumption (litres of pure alcohol per adult), Scotland and England and Wales, January 2013 to May 2019.

Figure S3 Weekly off-trade beer consumption (litres of pure alcohol per adult), Scotland and England and Wales, January 2013 to May 2019.

Figure S4 Weekly off-trade cider consumption (litres of pure alcohol per adult), Scotland and England and Wales, January 2013 to May 2019.

Figure S5 Weekly off-trade fortified wine consumption (litres of pure alcohol per adult), Scotland and England and Wales, January 2013 to May 2019.

Figure S6 Weekly off-trade RTD consumption (litres of pure alcohol per adult), Scotland and England and Wales, January 2013 to May 2019.

Figure S7 Weekly off-trade perry consumption (litres of pure alcohol per adult), Scotland and England and Wales, January 2013 to May 2019.

Table S1 Change (%) in off-trade alcohol sales in Scotland in the year after MUP was implemented, by beverage category (unadjusted, no control).

Table S2 Change (%) in off-trade alcohol sales in England and Wales in the year after MUP was implemented in Scotland, by beverage category (unadjusted, no control).

Table S3 Change (%) in off-trade alcohol sales in Scotland in the year after MUP was implemented, by beverage category (unadjusted, controlled).

Table S4 Change (%) in off-trade alcohol sales in Scotland

in the year after MUP was implemented, by beverage category (adjusted, controlled).

Table S5 Change (%) in difference between off-trade alcohol sales in Scotland and England and Wales in the year after MUP was implemented in Scotland, by beverage category (unadjusted).

Table S6 Change (%) in difference between off-trade alcohol sales in Scotland and England and Wales in the year after MUP was implemented in Scotland, by beverage category (adjusted).

Table S7 Change (%) in off-trade alcohol sales (after uplift for Aldi and Lidl) in Scotland in the year after MUP was after uplift for Aldi and Lidl, by beverage category (unadjusted, no control).

Table S8 Change (%) in off-trade alcohol sales (after uplift for Aldi and Lidl) in England and Wales in the year after MUP was implemented in Scotland, by beverage category (unadjusted, no control).

Table S9 Change (%) in off-trade alcohol sales (after uplift for Aldi and Lidl) in Scotland in the year after MUP was implemented, by beverage category (adjusted, controlled).

Table S10 Change (%) in off-trade alcohol sales (all alcohol) in NE England, NW England and Scotland (with NE England and NW England as control) in the year after MUP was implemented in Scotland.

Table S11 Change (%) in off-trade alcohol sales (all alcohol) in the year after MUP was implemented in Scotland using the Unobserved Components Method (UCM).

Table S12 Change (%) in all alcohol sales (off- and on-trade sales combined) in the year after MUP was implemented in Scotland, by beverage category (adjusted, controlled).

Table S13 Change (%) in on-trade alcohol sales in the year after MUP was implemented in Scotland, by beverage category (unadjusted, uncontrolled).

Table S14 Change (%) in on-trade alcohol sales in England & Wales in the year after MUP was implemented in Scotland, by beverage category (unadjusted, uncontrolled).

Table S15 Change (%) in the variability of off-trade alcohol sales in the year after MUP was implemented in Scotland.

Figure S8 Ildi and Lidl market share estimates in Scotland and England & Wales for all alcohol, 2011–2019.