ALCOHOL RESEARCH UK

Alcohol outlet density and alcohol-related hospital admissions in England: a geographical analysis

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EXECUTIVE SUMMARY

The purpose of our study was to investigate if alcohol outlet density was associated with hospital admissions for alcohol-related conditions in a national (English) small area level ecological (geographical) study (i.e. a study design which allowed us to examine if areas with more outlets had higher admissions). We used hospital admissions data from 2002/03 to 2013/14 and data on alcohol outlets from two market research companies.

We examined associations at the Lower Layer Super Output Area (LSOA) level between the densities of six categories of alcohol outlets and hospital admissions due to acute or chronic conditions wholly or partially attributable to alcohol consumption (LSOAs are small geographically defined areas used in the population census). We calculated outlet density which we defined as the number of outlets within a 1-km radius of a residential postcode centroid (the postcode centroid is the grid reference for the centre of a postcode). As there were several postcode centroids within each LSOA, we used the average for all postcodes within each LSOA. There were 32,482 LSOAs in England.

After adjustment for a range of potential confounders, we found several positive associations, with higher admission rate ratios mainly observed in the highest density categories by quartile (quartiles divide LSOAs into four categories, with an equal number of LSOAs in each category).

With regard to on-trade outlets, pubs, bars and nightclubs were associated with higher admissions of both acute and chronic conditions wholly attributable to alcohol, with increases in rate ratios of 13% (11-15%) and 22% (21-24%) in the highest, relative to the lowest, density category for acute and chronic conditions respectively. Restaurants were also associated with higher admissions of both acute and chronic conditions wholly attributable to alcohol, with increases of 9% (7-10%) and 9% (7-11%) respectively in the highest density category. Other on-trade outlets were also associated with higher admissions of both acute and chronic conditions wholly attributable to alcohol, with increases of 12% (10-14%) and 19% (17-21%) respectively in the highest density category.

With regard to off-trade outlets, convenience stores were associated with higher admissions of both acute and chronic conditions wholly attributable to alcohol, with increases of 10% (9-12%) and 7% (6-9%) respectively in the highest density category. Supermarkets, however, were only associated with a modest increase in admissions of acute and chronic conditions wholly attributable to alcohol, with increases of 3% (2-4%) and 4% (3-5%) respectively in the highest density category. Other off-trade outlets were only associated with an increase in admissions for chronic conditions wholly attributable to alcohol, with an increase of 11% (9-12%) in the highest density category.

Specific conditions wholly attributable to alcohol (acute alcohol intoxication; intentional self-poisoning using alcohol; mental and behavioural disorders due to alcohol; alcoholic liver disease) generally displayed admission patterns broadly

consistent with those described above. For conditions partially attributable to alcohol, however, there were generally no strong patterns of association with the outlet categories.

The strength of associations for on-trade outlets generally increased with increasing age but there were no consistent trends with age for off-trade outlets. Patterns of association were generally similar in men and women, apart from a few differences. There were no consistent patterns to indicate that associations increased with increasing levels of socioeconomic deprivation. There was also no evidence of lagged effects of outlet density on admissions. Use of radii larger than 1-km to calculate outlet density diminished or abolished positive associations. Adjusting for residual spatial autocorrelation did not substantially alter the general pattern of associations observed.

INTRODUCTION

Purpose of study

Availability of alcohol is a major policy issue and one of the availability factors is the density of alcohol outlets in a geographical area. However, whilst numerous international research studies on alcohol outlet density have examined associations with consumption and with crime and disorder (Popova et al., 2009; Campbell et al., 2009; Bryden et al., 2012; Holmes et al., 2014), few have examined associations with alcohol-related hospital admissions (Tatlow et al., 2000; Livingston, 2011; Stockwell et al., 2013; Fone et al., 2016; Richardson et al., 2015).

The costs of alcohol-related health harms to national health services are substantial. There are an estimated 800,000 alcohol-attributable hospital admissions per year in England and the total yearly cost of alcohol-related harm to the National Health Service (NHS) has been estimated to be in the region of £2.7 billion (Department of Health, 2008a; 2008b).

Patterns in alcohol outlet density have changed in recent years in England. There has been a general decline in the number of local pubs but this has been accompanied by an increase in off-premise outlets, including supermarket outlets. There has also been an increase in the concentration of bars in city centres. These observations are from as yet unpublished work carried out in our department.

A shift is occurring in UK alcohol licensing policy with increasing emphasis on controlling alcohol consumption and harm by bringing public health bodies or considerations into licensing decision-making (Licensing Act, 2005; HM Government, 2012). Local authorities have been given powers to control alcohol outlet density through cumulative impact policies in England and Wales and licensing statements in Scotland but the consideration of chronic harms in licensing policy is currently hampered by the very limited evidence base (SHAAP, 2011).

The purpose of our study was to investigate if alcohol outlet density was associated with hospital admissions for alcohol-related conditions in a national (English) small area level ecological study. The key novel aspects of our study were the investigation of hospital admissions for a range of alcohol-related conditions, incorporation of both cross-sectional and longitudinal data, the use of small geographical areas, and examination of associations with different types of alcohol outlets.

Literature review

Several studies have been carried out to investigate associations between alcohol outlet density, alcohol consumption and harm, summarised in systematic reviews (Popova et al., 2009; Campbell et al., 2009; Bryden et al., 2012; Holmes et al., 2014). Much of this literature is cross-sectional in nature. The great majority examined effects on alcohol consumption, several examined effects on crime and disorder, and a few examined links with child abuse, sexually transmitted infection and

suicide. Very few studies, however, examined the effects on chronic harms, which typically include conditions such as alcoholism and alcoholic liver disease.

Alcohol outlets may be classified into two broad groups: (i) on-trade outlets comprise outlets where alcohol can be purchased and consumed on the premises (e.g. pubs); (ii) off-trade outlets are sales outlets where alcohol can be purchased but not consumed on the premises (e.g. convenience stores). Early studies examining chronic effects used large geographical areas as the units of analysis, e.g. a state level analysis in the USA found that on-premise outlet density was correlated with liver cirrhosis mortality (Colon, 1981). More recently, Theall et al found an association between neighbourhood-level off-premise alcohol outlet density and self-reported liver problems in Los Angeles and Louisiana (Theall et al., 2009). Two recent studies in British Columbia both found that increases in the density of off-trade outlets were associated with increases in alcohol-related mortality (Stockwell et al., 2011; Zhao et al., 2013).

Few published studies to date have examined associations between outlet density and hospital admissions (Tatlow et al., 2000; Livingston, 2011; Stockwell et al., 2013; Fone et al., 2016; Richardson et al., 2015). Alcohol-related hospital admissions are useful to study because they allow both acute and chronic effects of outlet density to be examined. Livingston, in a Melbourne study, found that on-trade outlets were strongly associated with assault admissions (an acute effect) but were also associated with chronic alcohol induced conditions to a lesser extent, whilst off-trade outlets were strongly associated with both assaults and chronic alcohol induced conditions (Livingston, 2011). Stockwell et al (2013) examined a broader group of conditions in British Columbia and found associations between off-trade outlets (privately owned, rather than government owned and run, liquor stores) and admissions for both acute and chronic conditions but no significant associations with on-trade outlets. Tatlow et al (2000) found an association between outlet density and alcohol-related hospital admissions in San Diego County but did not distinguish between acute and chronic conditions and did not present results separately for on-trade and off-trade outlets.

With regard to evidence on outlet density and harm in the UK, there are two recent studies of note. Fone et al (2016) examined the association between alcohol outlet density and alcohol consumption, hospital admissions, accident and emergency attendances and crime in Wales and found evidence of association with all these outcomes. They were not able, however, to differentiate between on-trade and off-trade outlets and did not distinguish between admissions for acute and chronic conditions related to alcohol.

Richardson et al (2015) examined the association between on-trade and off-trade outlet density and admissions and mortality in the four largest cities in Scotland. They combined all conditions wholly attributable to alcohol but also examined alcoholic liver disease separately as an indicator of chronic harm and found associations with both on-trade and off-trade density. They did not however examine sub-categories of on-trade and off-trade outlets.

In addition, there are two online reports examining outlet density in the UK. Chiang found an association between alcohol outlet density and crime in Glasgow but the study did not differentiate between on-trade and off-trade outlets (Chiang, 2010). A mapping exercise of alcohol outlet density was carried out in the East Midlands but associations with outcomes were not examined (Langley and Bellamy, 2011).

We recently completed work on a joint Medical Research Council / Economic and Social Research Council (MRC/ESRC) funded strategic programme grant (Interdisciplinary Alcohol Policy Effectiveness Research Programme) which includes an element examining alcohol outlet density and alcohol consumption.

Theoretical considerations and hypotheses investigated

Robust theoretical models of the relationship between alcohol outlet density and alcohol-related harm are still being developed and these often reflect empirical analyses by focusing on the relationship between on-trade density and acute harms or violence (Gruenewald, 2008; Livingston et al., 2007). Models where the proposed mechanism for the outlet density impact does not necessarily require high alcohol consumption, for example where violence occurs due to collisions between drinkers exiting several densely situated on-trade outlets, are relevant for explaining acute harms (Hough and Hunter, 2008).

Economic models suggest outlet density may impact on chronic harms through increased consumption. A key proposition is that increased density lowers the 'full cost' of alcohol purchases by increasing average proximity to outlets and thus reducing travel, energy and time costs (Livingston et al., 2007). Competition between densely situated outlets may also exert downward pressure on prices or lead to diversifications of the market which stimulate consumption by better matching supply and demand (Gruenewald, 2006).

The above theoretical considerations and previous empirical results informed the hypotheses we investigated. These included the hypotheses that: (i) on-trade outlets (specifically bars and pubs) would be associated with acute alcohol related admissions, based on theoretical considerations outlined above and on previous results (Livingston, 2011); (ii) on-trade outlets would also be associated with admissions for chronic alcohol-related conditions, based on results from previous studies (Livingston, 2011; Richardson et al., 2015); (iii) off-trade outlets would be associated with chronic alcohol-related conditions, and that this association would be most clearly observed for admissions which were wholly attributable to alcohol, such as chronic liver disease, based on theoretical considerations outlined above and on results from previous studies (Livingston, 2011; Stockwell et al., 2013; Richardson et al., 2015); and (iv) off-trade outlets would also be associated with acute harms, based on previous research and theory supporting this link, which includes violence related to high alcohol consumption (e.g. domestic violence and local street violence) and "pre-loading" especially from purchase of cheap alcohol from off-licences and convenience stores (Livingston, 2011).

We previously found that alcohol-related mortality rates in England were much higher in men, reached a peak in the middle-aged adult population and were substantially higher in the most socioeconomically deprived areas (Erskine et al., 2010). We therefore investigated associations in deprived and non-deprived areas, in men and women, and young and older adults and anticipated that associations would be stronger in more deprived areas, in men, and that stronger associations would be seen for acute harms in younger adults and for chronic harms in older adults. The geography of urban and rural areas is quite different, with more dispersed populations and outlets in rural areas. We therefore also planned to investigate associations in urban and rural areas.

METHODS

Study design and area of study

We used a small area level ecological (geographical) study design, with all Lower Layer Super Output Areas (LSOAs) in England used as the geographical units of analysis. LSOAs were census areas created in the 2001 national census, with approximately 1500 people per LSOA. There were 32,482 LSOAs and they were the smallest spatial units at which anonymised hospital admission data were available.

The LSOA is a finer spatial scale than those used in some of the previously published ecological studies on alcohol outlet density and hospital admissions, where the average population in the geographical units of analysis were approximately 17,000 and 52,000 in two studies (Livingston, 2011; Stockwell et al., 2013) and >10,000 in the third (Tatlow et al., 2000), which did not provide further details. Recent UK studies used spatial scales similar to the LSOAs we used (Fone et al., 2016; Richardson et al., 2015).

Data on alcohol outlets

There was no central register of premises holding a licence to sell alcohol in England. Records were held by local authority licensing boards in a wide range of forms and were often not readily publicly available. Previous studies in Scotland and Wales had attempted to collect and combine outlet data from local authorities directly (Shortt et al., 2015; Fone et al., 2016). The process, however, appeared to have been very time-consuming, encountering wide variation in the level of information held about each outlet and in the quality of the data retrieved. An alternative source for such data was market research companies working in the alcohol sector. Two such companies, CGA Strategy, which worked in the on-trade sector, and Nielsen, which worked in the off-trade sector, maintained databases of all outlets selling alcohol in England. We purchased extracts from these databases covering the years 2003, 2007, 2010 and 2013 from CGA Strategy, which maintained and updated both the on-trade and off-trade outlet databases. These data included information on the type of outlet and its full postcode.

Both databases were collated from a broad range of sources including local authorities, third party business directories and the Royal Mail Postal Address File, alongside data supplied by alcohol producers, wholesalers and retailers. They were updated monthly by a full-time research team using a combination of online and phone enquiries and fieldwork to identify new outlets, closures of existing outlets, changes in ownership and changes in outlet type. CGA estimated that the databases included 98% of all outlets in England. Each year approximately 85% of all outlets, including 95% of pubs, were actively confirmed to be trading. Data from these companies have been used by Public Health England, an executive agency of the Department of Health responsible for health promotion and protection (Public Health England, 2017).

Data on the outlet type for every outlet selling alcohol was available in a 69-category classification for the on-trade data and an 8-category classification for the off-trade. The CGA on-trade classification included categories such as 'Branded food pub', 'Cricket club', 'Hotel' and 'Chinese restaurant'. For the purposes of this analysis we reduced this classification into three broad categories: (i) pubs, bars and nightclubs (including café and wine bars); (ii) all restaurants; and (iii) all other on-trade outlets (including sports and social clubs, hotels, and casinos). There were minor adjustments to CGA's 69 categories over the period from 2003-13, but these did not affect the three categories outlined above.

The off-trade classification for outlets included categories such as 'Supermarket', 'Independent' and 'Wholesaler'. For the purposes of this analysis we reduced this into three broad categories: (i) supermarkets (typically having a floor area in excess of 280m^2); (ii) convenience stores (typically having a floor area of less than 280m^2); and (iii) all other off-trade outlets (including garage forecourts, specialist off-licences and wholesalers).

There were significant revisions to data collection processes between 2010 and 2013, leading to a number of outlets being reclassified. This revision also included the addition of the 'Wholesaler' and 'Forecourt' categories, where previously these categories were grouped together under 'other'. Following discussions with CGA and Nielsen, we agreed a protocol to account for these revisions in the data. All outlets which were identified in the data across multiple time points, including 2013, were given the outlet's 2013 classification across all previous time points. Thus an outlet appearing as 'Other' in 2010 and 'Forecourt' in 2013 was classified as a 'forecourt' in both years. The only exception to this change was outlets classified as 'Independent' prior to 2013, which were not reclassified. This was due to significant changes in this sector of the market between 2010 and 2013, including the closure of a number of large national chains, such as 'Thresher' and 'Victoria Wines', many of whose sites were redeveloped as convenience stores. We therefore assumed that changes in classification for these outlet types represented a genuine change of use.

In order to measure exposure to alcohol outlets, we calculated outlet density for each outlet category at the LSOA level. We did this by first counting the number of outlets within a 1-km radius around each of the 1.2 million residential postcodes in England. We used the full postcode of outlets to determine their grid reference and the postcode centroids of residential postcodes for this process (the postcode centroid is the grid reference for the centre of a postcode). We then calculated the average count for all postcodes within an LSOA (there are approximately 35 postcodes per LSOA), weighting the average by the postcode population headcount (weighting "pulls" the average closer to the outlet counts of postcodes with larger numbers of people). Approximately 90% of postcodes were in existence at both the 2001 and 2011 censuses and for these, we used the average of postcode population counts from both censuses. For the remaining postcodes, we used population counts from the 2011 census.

Our main LSOA level exposure measure was therefore the number of outlets within a 1-km radius of a residential postcode centroid, averaged for all postcodes within an LSOA. This approach to the density calculation did not constrain the density count to areas within an LSOA boundary and is similar to the approach we have used previously to obtain average air pollution exposures for populations within small geographical areas (Brindley et al., 2005; Maheswaran et al., 2012). We used a 1-km radius because the National Travel Survey indicated that 1 km is the average walking journey length (National Travel Survey, 1999). In a subset of the data, we also examined the effects of using other radii (250m, 3-km and 5-km). A Competition Commission report indicated that 80-90% of consumers lived within 5km of convenience stores (Competition Commission, 2008).

Whilst we analysed associations between all six outlet types and hospital admissions, we anticipated that associations seen with on-trade outlets would be specific to pubs, bars and nightclubs and not restaurants or other premise types. We also anticipated that associations with off-trade outlet density would be specific to convenience stores and possibly other off-trade outlets and would be unlikely to be seen for supermarkets as the latter tend to serve large catchment areas, particularly with home delivery, are used by the majority of the population and are therefore unlikely to exert a strong local density effect.

Hospital admissions data

Hospital Episode Statistics (HES) for hospital admissions in England for the 12-year period 2002/03 to 2013/14 (financial years 1st April to 31st March) were supplied by NHS Digital. HES data are routinely collected administrative data that record any hospital activity. The pseudo-anonymised information supplied included age, sex and location of residence, along with up to 20 diagnosis fields. Data comprised individual 'episodes', each of which is a continuous period of care under a single consultant doctor during an admission.

We followed the approach taken by Public Health England for identifying alcohol-related admissions (Public Health England, 2014). First, the data set was "cleaned" to address some known issues with HES and the process is described in the Supplementary Information, with a table showing the effect of each stage of the process on episode counts. Only episodes that were finished, and were 'ordinary' (non-elective admissions or an elective admission expected to remain in hospital overnight), day case (elective admissions not requiring an overnight stay) or maternity admissions were included. We removed admissions with an age at the beginning of admission outside the range of 0 to 120, or where the sex was not recorded as male or female. We only considered admissions with an English LSOA of residence. The percentage of episodes which remained following cleaning over the 12-year study period was 89.72%.

Alcohol-related conditions were weighted using Public Health England's alcohol attributable fractions (AAF) (Jones and Bellis, 2013; Public Health England, 2014). An AAF represents the proportion of a condition that is attributable to alcohol consumption. AAFs were age- and sex-specific, and were adjusted for alcohol consumption. Conditions with a negative AAF, which suggest a protective effect of

alcohol, were excluded. We identified alcohol-related admissions using an approach guided by Public Health England's 'narrow' measure. Our approach is described in the paragraph below.

Each HES episode can contain up to 20 diagnosis fields, with the diagnosis in the first diagnosis position being the primary diagnosis (diagnoses were coded using the International Classification of Diseases, 10th Revision (ICD-10) throughout the study period). The narrow measure was calculated based on the primary diagnosis of an episode, with external conditions taken from secondary diagnostic positions 2 to 14 (external conditions, which are environmental causes of injury occurring outside the body, do not feature as the primary diagnosis). During the time period studied, the number of diagnostic positions was expanded from 14 to 20, but we only considered up to 14 so that there was consistency throughout the period. Where there were multiple alcohol-related conditions recorded within an episode, we classified the episode using the condition with the largest AAF. If there were two conditions with the same AAF, we used the condition from the lowest diagnostic position (i.e. closest to diagnosis position 1). An admission could comprise more than one episode of care if patients are transferred from the care of one consultant to another within the same admission. However, 86.7% of all admissions only contained a single episode and we considered only the first episode from each admission.

We used four outcome measure categories of alcohol-related harm based on previous research (Jones and Bellis, 2013; Stockwell et al., 2013; Public Health England, 2014). These were (i) acute conditions wholly attributable to alcohol consumption; (ii) chronic conditions wholly attributable to alcohol consumption; (iii) acute conditions partially attributable to alcohol consumption; and (iv) chronic conditions partially attributable to alcohol consumption. The Supplementary Information presents which conditions were included in each of the above categories, based on Public Health England's approach. For acute conditions, we considered only emergency admissions. For chronic conditions, we combined emergency and non-emergency admissions.

In addition, we also examined four specific conditions which were wholly attributable to alcohol consumption, two acute and two chronic. These were the most common specific conditions within the acute and chronic wholly attributable to alcohol categories. The two acute conditions were (i) 'Acute Intoxication subcategory of Mental and Behavioural Disorders due to use of Alcohol' (ICD-10 code F10.0); and (ii) 'Intentional self-poisoning due to alcohol' (ICD-10 code X65). The two chronic conditions were (i) 'All other Mental and Behavioural Disorders due to use of Alcohol' (ICD-10 code F10.1-F10.9); and (ii) 'Alcoholic Liver Disease' (ICD-10 code K70).

We also extracted episodes which were not related to alcohol. Admission to hospital is influenced by a wide variety of factors. These include a hospital's admission policies, availability of hospital beds, the level and quality of primary and community care in a local area, geographical access to health facilities and local variation in cultural and social norms influencing illness behaviour. We used admissions for non-alcohol related admissions as a proxy for these other factors.

In addition to the above, one hypothesis that might potentially explain any association between outlet density and health outcomes is that outlets cluster in "unhealthy" areas where illness levels are high and harmful health behaviours such as smoking are prevalent. We therefore used lung cancer admissions as a proxy for such areas.

Socioeconomic deprivation, urban-rural status and Standard Regions

We used the Income Domain of the index of Multiple Deprivation (IMD) as an indicator of socioeconomic deprivation at the small area level. The IMD is a widely used national indicator of deprivation in England available at the LSOA level. We used the Income Domain because the overall index also included a Health Domain.

We used the ONS urban-rural classification which assigned 2001 based LSOAs to one of three categories: (i) urban; (ii) rural (town and fringe); and (iii) rural (village; hamlets and isolated dwellings).

We included English Regions to take into account any regional effects. There were nine Regions with LSOAs assigned to one of these nine regions (North East; North West; Yorkshire and the Humber; East Midlands; West Midlands; East of England; London; South East; South West).

Statistical analysis

For the main statistical analyses, we employed standard Poisson regression methods in SAS using observed and expected counts. We grouped admissions by LSOA, year and sex to generate observed counts. We calculated the corresponding expected admission counts using indirect internal standardisation, standardising by five-year age band. Rates for standardisation were generated, using data for all 12 years combined, for each of the eight outcome categories described previously. Estimated population denominators by LSOA, year, sex and five-year age band were obtained from the Office for National Statistics (ONS). As there were very few alcohol-related admissions among children, the main analyses were restricted to people aged 15+ years.

We calculated observed and expected counts for non-alcohol related emergency and non-emergency admissions. We used the emergency admissions in the analyses of acute alcohol-related admissions and emergency and non-emergency admissions combined in the analyses of chronic alcohol-related admissions.

We also calculated observed and expected counts for lung cancer admissions. LSOA counts by year and sex were however very low. The LSOA lung cancer variable was therefore modified by combining the counts for all 12 years and both sexes to generate a single observed and a single expected count for each LSOA.

With regard to socioeconomic deprivation, we used the IMD income score from 2007 in the main analysis as this was from around the mid-point of the 12-year time span we examined. We assigned LSOAs to categories using quintiles of the score.

As outlet densities were only available for four of the 12 years, we used linear interpolation to derive values for years in between the years with available data e.g. LSOA values for 2004 to 2006 were calculated using outlet densities calculated using data for 2003 and 2007. Values for 2002 were derived by extrapolating the linear trend derived from the 2003 and 2007 values. Any resulting negative outlet density values for 2002 were set to zero.

In the Poisson regression models, we entered the log of the expected counts of alcohol-related admissions as the offset. We entered Region, deprivation category, urban-rural category, sex and year as categorical variables. Year was included to control for general time trends across the study period. We entered the log of observed divided by expected counts of non-alcohol related admissions and of lung cancer admissions as continuous variables.

We initially examined outlet densities as continuous variables. However, inspection of residual deviances clearly indicated non-linear associations. We therefore used quartiles to categorise outlet density for use in the analyses (Quartiles divide LSOAs into four categories with an equal number of LSOAs in each category. This ensures that results are not based on only a small number of LSOAs in some categories). The quartile cut-offs were generated using the distribution of values from all 12 years in order to use a single consistent set of cut-offs by outlet type for the whole dataset.

Following the main analysis which examined data for men and women combined, we repeated the analyses separately for men and women to examine if there were gender differences in the associations observed. We examined effects in different broad age categories to investigate if associations varied by age, and also examined if associations varied by level of socioeconomic deprivation. In addition, we also examined the effects of changing the distance radius used for calculating outlet density on associations observed.

Lag effects have been reported in relation to alcohol prices. Stockwell et al, for example, observed that alcohol price changes exerted effects observable at zero lag for admissions for acute alcohol related conditions but which only became apparent from a two-year lag onwards for admissions for chronic alcohol related conditions (Stockwell et al., 2013).We therefore examined if there were similar patterns in relation to outlet density and admissions.

Although we included a range of other covariates to take into account potential spatial confounding, residual spatial autocorrelation (i.e. the statistical non-independence of neighbouring geographical areas) could have existed as a result of largely unobserved factors e.g. "supplier side" factors such as price and marketing and individual level factors such as attitudes to alcohol, drinking behaviours and demand for alcohol. We therefore carried out sensitivity analyses using Bayesian hierarchical modelling incorporating unstructured and spatially

structured random effects (Besag et al., 1991). We used an adjacency matrix where LSOAs with common boundaries were classified as neighbours.

Results are presented as rate ratios with 95% confidence intervals (95%CI). We inflated confidence intervals to take account of any overdispersion.

RESULTS

Alcohol outlet counts

Counts of outlets by category for the years 2003, 2007, 2010 and 2013 are shown in Table 1. These were the four years for which CGA and Nielsen data were available.

With regard to on-trade outlets, the number of pubs, bars and nightclubs decreased from 55,105 in 2003 to 49,940 in 2013, a decrease of 9%. The other on-trade outlets category showed an even larger decrease, from 48,727 to 36,191, a 26% decrease. However, the number of restaurants licenced to sell alcohol increased from 18,410 to 21,433, an increase of 16%.

In contrast, off-trade outlet counts increased in all three categories. The increase was most striking in relative terms for convenience stores, from 8,083 to 16,467, an increase of 104%. Supermarket numbers increased from 4,417 to 5,859, a 33% increase. Other off-trade outlets also increased from 20,892 to 23,134, an increase of 11%.

Table 1. Number of outlets by category and years for which CGA and Nielsen data were available; England.

Outlet category	**Years CGA and Nielsen data were available**				
	2003	2007	2010	2013	% change 2013-03
On-trade outlets					
Pubs, bars, nightclubs	55,105	56,204	53,487	49,940	-9%
Restaurants	18,410	18,849	19,160	21,433	16%
Other on-trade outlets	48,727	45,848	43,115	36,191	-26%
Off-trade outlets					
Supermarkets	4,417	5,101	6,072	5,859	33%
Convenience stores	8,083	11,225	11,901	16,467	104%
Other off-trade outlets	20,892	22,166	22,874	23,134	11%

Distribution of alcohol outlet densities

The distribution of outlet densities for each of the six outlet categories is shown in Table 2. Densities shown were measured as the number of outlets within a 1-km radius of a residential postcode centroid and the average calculated for all postcodes within an LSOA for each year with CGA and Nielsen data, and interpolation between years (and extrapolation to 2002) as described in the Methods section. Medians with interquartile ranges (IQR) are presented as the distributions had a positive skew (Median is the middle value in a distribution values. A mean (or average) density will be "pulled" or skewed towards a higher average value by the relatively small number of LSOAs with very high outlet densities e.g. in city centres).

The median was highest for pubs, bars and nightclubs, at 4.79 (IQR 2.39 - 10.47) and lowest for supermarkets, at 0.74 (0.00 - 1.70).

Table 2. Distribution of outlet densities (number of outlets within a 1-km radius of a postcode centroid, averaged for all postcodes within an LSOA) in England, 2002-13.

Outlet category	**Median (IQR)**
On-trade outlets	
Pubs, bars, nightclubs	4.79 (2.39 - 10.47)
Restaurants	1.02 (0.03 - 4.06)
Other on-trade outlets	4.28 (1.98 - 8.13)
Off-trade outlets	
Supermarkets	0.74 (0.00 - 1.70)
Convenience stores	1.86 (0.81 - 3.23)
Other off-trade outlets	3.05 (1.03 - 6.87)
LSOAs in England (n)	**32,482**

Alcohol outlet density and socioeconomic deprivation

Table 3 shows the median (IQR) for outlet densities in relation to socioeconomic deprivation at the LSOA level.

The density of all six categories of outlets increased with increasing socioeconomic deprivation. The only slight variation to the progressive increase across deprivation categories was for restaurants, where the median for the highest deprivation category was lower than that for the second highest deprivation category.

Table 3. Distribution of outlet densities (number of outlets within a 1-km radius of a postcode centroid, averaged for all postcodes within an LSOA) by deprivation category in England, 2002-13 (1=highest, and 5=lowest, deprivation category by quintile).

On-trade outlets			**Off-trade outlets**		
Pubs, bars, nightclubs			***Supermarkets***		
		Median (IQR)			Median (IQR)
Deprivation category	1	8.31 (4.00 - 18.98)	Deprivation category	1	1.09 (0.34 - 2.22)
	2	6.57 (3.48 - 13.30)		2	1.00 (0.14 - 2.00)
	3	5.00 (2.54 - 10.42)		3	0.76 (0.00 - 1.75)
	4	3.47 (1.68 - 6.99)		4	0.27 (0.00 - 1.07)
	5	2.93 (1.60 - 5.42)		5	0.20 (0.00 - 1.00)
Restaurants			***Convenience stores***		
		Median (IQR)			Median (IQR)
Deprivation category	1	1.49 (0.13 - 6.12)	Deprivation category	1	2.60 (1.41 - 4.23)
	2	1.85 (0.29 - 5.77)		2	2.32 (1.19 - 3.87)
	3	1.22 (0.07 - 4.50)		3	1.89 (0.84 - 3.24)
	4	0.77 (0.00 - 2.80)		4	1.24 (0.30 - 2.55)
	5	0.63 (0.00 - 2.26)		5	1.06 (0.33 - 2.18)
Other on-trade outlets			***Other off-trade outlets***		
		Median (IQR)			Median (IQR)
Deprivation category	1	6.50 (3.73 - 11.26)	Deprivation category	1	6.58 (3.18 - 12.66)
	2	5.65 (3.16 - 9.77)		2	4.33 (2.00 - 8.31)
	3	4.47 (2.00 - 8.36)		3	2.98 (1.00 - 6.39)
	4	2.97 (1.06 - 5.98)		4	1.90 (0.58 - 4.41)
	5	2.51 (1.08 - 4.82)		5	1.56 (0.57 - 3.26)

Admission counts and rates

Table 4 presents admission counts for years at the start and end of the study period (HES years 2002/03 and 2013/14) to illustrate the magnitude of counts in the eight outcome categories used in this analysis. As there were 32,482 LSOAs, the expectation was >1 admission per LSOA per year for chronic conditions wholly attributable to alcohol, and for both acute and chronic conditions partially attributable to alcohol. For acute conditions wholly attributable to alcohol, the expectation increased from <1 to >1. For specific conditions, however, all the expectations were <1.

The table also shows the percentage change in admissions between the start and end of the study period. All admissions attributable to alcohol increased. This ranged from 38% for chronic conditions partially attributable to alcohol to 161% for "Intentional self-poisoning due to alcohol (X65)".

The increase in total admissions for conditions wholly and partially attributable to alcohol combined was 51%. This, however, has to be seen in relation to the increase in non-alcohol related conditions of 39%, also provided in the table, reflecting the general increase in hospital admissions in England over time. This was in part explained by the 8% increase in the total population in England over the time period of the study.

The increase in the crude rate of admissions for conditions wholly and partially attributable to alcohol combined was 39% while the equivalent increase in non-alcohol related admissions was 28%.

Trends in crude rates over time for all eight outcome categories are shown in Figures 1 and 2. The graphs present separate rates for men and women. The graphs illustrate the general increase in admission rates over the study period in all eight outcome categories.

Rates were higher in men than in women for all outcome categories except for "Intentional self-poisoning due to alcohol (X65)" where rates were higher for women.

Table 4: Alcohol attributable admissions to hospital for conditions related to alcohol; England 2002/03 and 2013/14 (HES data years at the start and end of study period).

Conditions attributable to alcohol		**Year**		**% increase (2013/14 – 2002/03)**
		2002/03	**2013/14**	
Condition categories	Acute conditions wholly attributable to alcohol	23172	52291	126
	Chronic conditions wholly attributable to alcohol	34159	50142	47
	Acute conditions partially* attributable to alcohol	44589	63671	43
	Chronic conditions partially* attributable to alcohol	99478	137612	38
Specific conditions wholly attributable to alcohol	***Acute conditions***			
	Acute alcohol intoxication (F10.0)	7013	15546	122
	Intentional self-poisoning using alcohol (X65)	11966	31232	161
	Chronic conditions			
	Mental and behavioural disorders due to alcohol (F10.1-F10.9)	19375	26921	39
	Alcoholic liver disease (K70)	11135	16142	45
Admissions wholly and partially attributable to alcohol combined	Total Admissions	201,398	303,716	51
	Crude Rate (per 100,000)	402	560	39
Non-alcohol related admissions	Total Admissions	9,450,898	13,095,242	39
	Crude Rate (per 100,000)	18,849	24,127	28
Population		50,141,285	54,276,638	8

* Partially attributable conditions totals are a sum of fractions of admissions for conditions which are partially attributable to alcohol

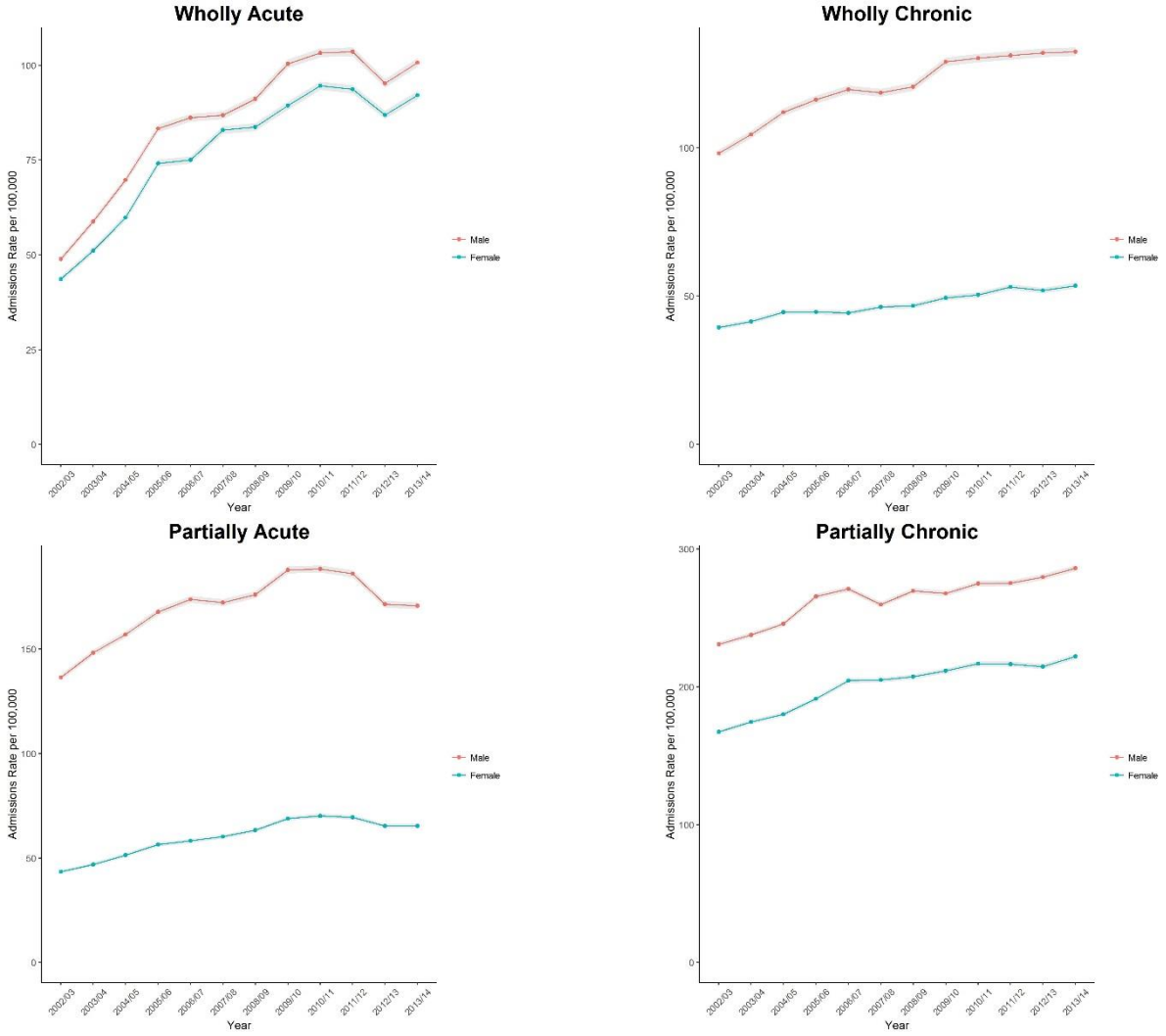

Figure 1: Crude rate per 100,000 (with shaded 95% Confidence Intervals) of hospital admissions by sex for England, 2002/03 to 2013/14: (i) wholly attributable acute conditions (titled: 'Wholly Acute'), (ii) wholly attributable chronic conditions ('Wholly Chronic'), (iii) partially attributable acute conditions ('Partially Acute'), (iv) partially attributable chronic conditions ('Partially Chronic').

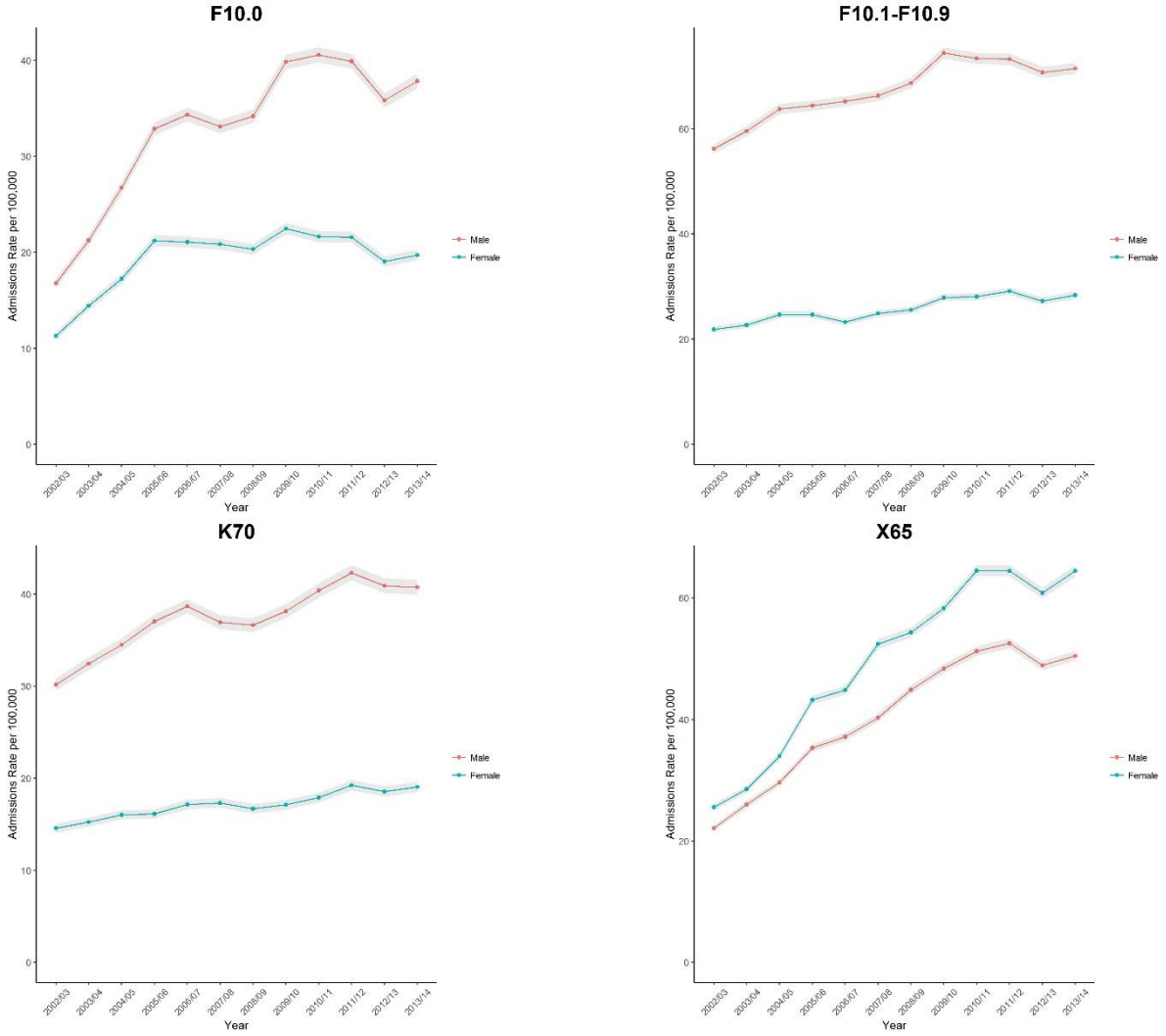

Figure 2: Crude rate per 100,000 (with shaded 95% Confidence Intervals) of hospital admissions by sex for England, 2002/03 to 2013/14: (i) Acute Intoxication subcategory of Mental and Behavioural Disorders due to use of Alcohol (titled: 'F10.0')', (ii) All other Mental and Behavioural Disorders due to use of Alcohol ('F10.1-F10.9'), (iii) Alcoholic Liver Disease ('K70'), (iv) Intentional self-poisoning due to alcohol ('X65').

Socioeconomic deprivation and admission rates

Admission rates over time in relation to socioeconomic deprivation at the LSOA level are shown in Figures 3 and 4 for all eight outcome categories. The figures present rates separately for men and women by deprivation category, using direct standardisation for age (five-year age bands) in order to adjust for any differences in age structure between deprivation categories.

The figures show that admission rates increased with increasing socioeconomic deprivation in all outcome categories.

The increases with increasing deprivation were greater for men than for women in all outcome categories except for "Intentional self-poisoning due to alcohol (X65)" where the socioeconomic differentials were similar in men and women.

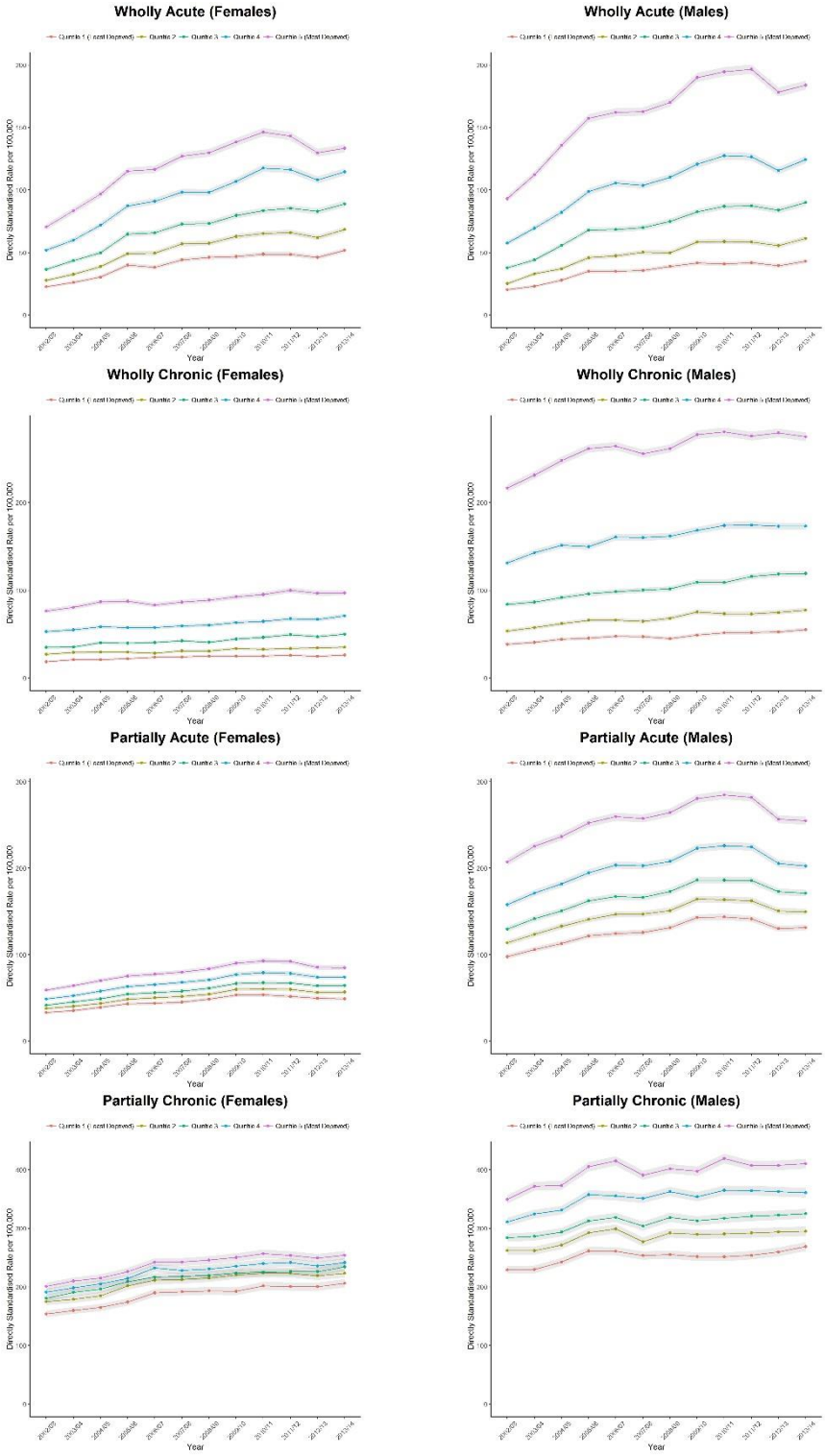

Figure 3: Directly standardised rate of hospital admissions for England split by deprivation quintile and condition type: (i) wholly attributable acute conditions (titled: 'Wholly Acute'), (ii) wholly attributable chronic conditions ('Wholly Chronic'), (iii) partially attributable acute conditions ('Partially Acute'), (iv) partially attributable chronic conditions ('Partially Chronic').

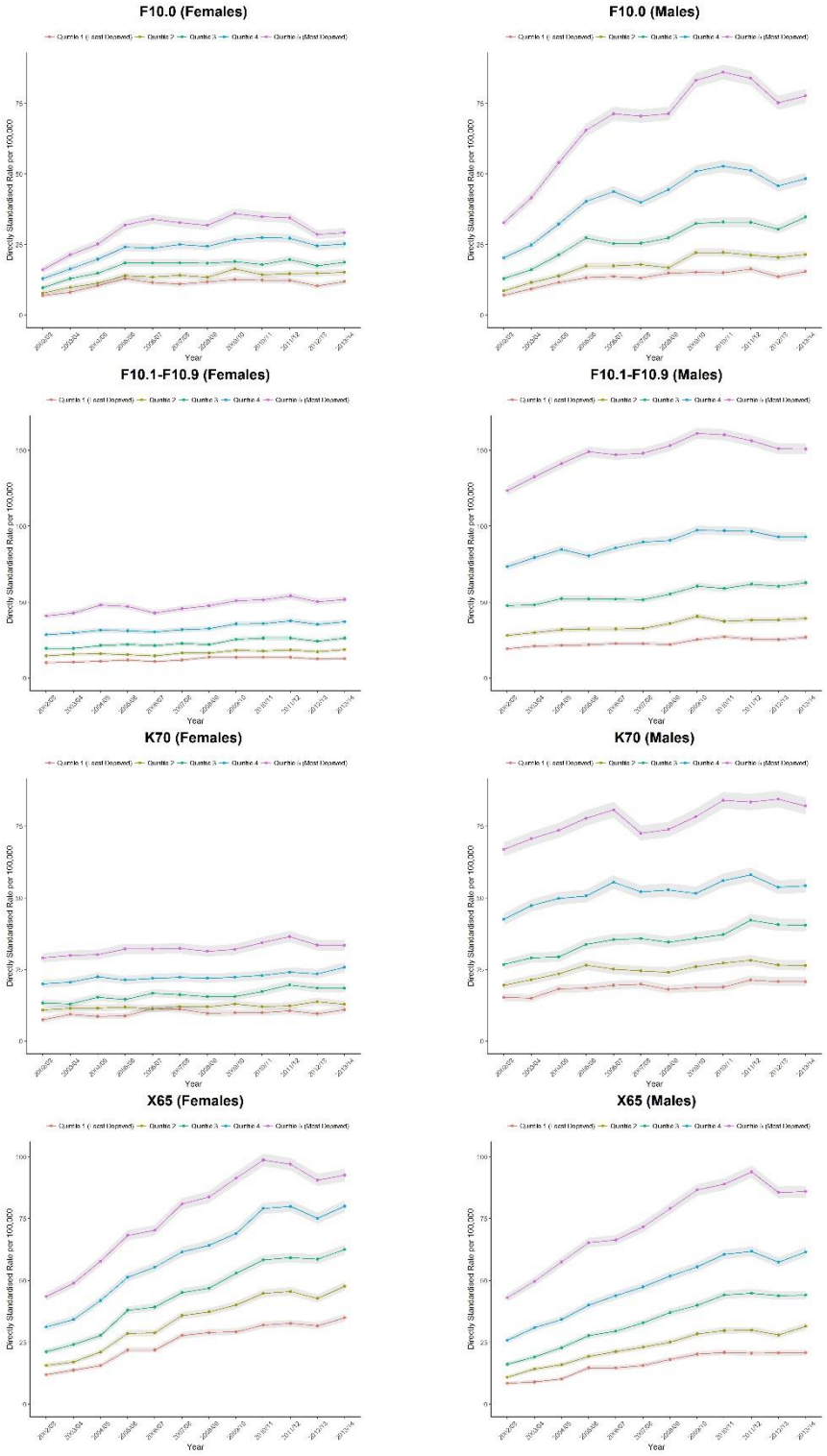

Figure 4: Directly standardised rate of hospital admissions for England of the most prevalent wholly attributable conditions: (i) Acute Intoxication subcategory of Mental and Behavioural Disorders due to use of Alcohol (titled: 'F10.0')', (ii) All other Mental and Behavioural Disorders due to use of Alcohol ('F10.1-F10.9'), (iii) Alcoholic Liver Disease ('K70'), (iv) Intentional self-poisoning due to alcohol ('X65'). Note: Scales are same for each sex, but vary by condition.

Associations between outlet density and hospital admissions

The main results are shown in Table 5, which presents the adjusted admission rate ratios (95% CI) for both sexes combined for all eight outcome categories. The results for men and women separately, also for all eight outcome categories, are presented in Tables 6 and 7 respectively.

The results broken down by broad age band are shown in Tables 8 and 9. The results by socioeconomic deprivation are shown in Tables 10 and 11. Results of investigation of lagged effects are presented in Tables 12 and 13. All these show results for two outcome categories – acute and chronic conditions wholly attributable to alcohol.

Results using different distance radii are shown in Table 14 whilst results of spatial analyses are presented in Table 15. These two sets of analyses were carried out using one outcome category – acute conditions wholly attributable to alcohol.

The confidence intervals were generally very narrow because the study was based on a very large dataset (national data over a 12-year period). The description of the results therefore focusses on patterns of association. (This avoids giving emphasis to very small percentage increases or decreases in rate ratios which could be considered "statistically significant" because the narrow confidence intervals exclude 1.) All the results are based on examination of associations using categories of outlet density by quartile in view of the non-linear associations observed, as mentioned in the Methods section. The lowest density category was used as the baseline (reference) category.

Main associations

The main associations are shown in Table 5.

With regard to acute conditions wholly attributable to alcohol, rate ratios were clearly the highest in the highest outlet density categories for all three on-trade outlet categories. For pubs, bars and nightclubs, the admission rate ratio was 13% (11-15%) higher in the highest, relative to the lowest, density category. The increase was 12% (10-14%) for other on-trade outlets in the highest density category. The increase was 9% (7-10%) for restaurants in the highest density category.

With regard to off-trade outlets, a clear association was seen for convenience stores, with a 10% (9-12%) higher admission rate ratio for acute wholly attributable conditions in the highest density category. For supermarkets, however, there was only a small increase of 3% (2-4%) in the highest density category, whilst for other off-trade outlets, there appeared to be a decrease in the rate ratio in the highest relative to the lowest density category.

With regard to chronic conditions wholly attributable to alcohol, there were larger increases in admission rate ratios for two of the on-trade categories when compared with acute wholly attributable conditions. For pubs, bars and nightclubs, the admission rate ratio was 22% (21-24%) higher in the highest density category,

whilst for other on-trade outlets, the admission rate ratio was 19% (17-21%) higher in the highest density category. The increase in admission rate of 9% (7-11%) for restaurants in the highest density category was however similar to that seen for acute conditions wholly attributable to alcohol described above.

For off-trade outlets, the increase in the admission rate ratio in the highest density category for convenience stores of 7% (6-9%) was marginally less than that described previously for acute conditions wholly attributable to alcohol. For supermarkets, the percentage increase was similar, at 4% (3-5%). For other off-trade outlets, however, a positive association was seen with an increase of 11% (9-12%) in the highest category, unlike the negative association seen with acute wholly attributable conditions.

For acute and chronic conditions partially attributable to alcohol, there was generally no strong evidence of association with any of the alcohol outlet categories. The only exception was for pubs, bars and nightclubs, where the admission rate ratio for chronic partially attributable conditions in the highest density category was 6% (6-7%) higher relative to the rate in the lowest density category.

For the two specific acute wholly attributable conditions, the pattern of associations with the on-trade categories was broadly in keeping with the pattern for acute wholly attributable conditions as a whole, except for restaurants where there was a stronger association with "Acute alcohol intoxication (F10.0)" with a 22% (19-25%) increase in the highest density category, and a weaker association with "Intentional self-poisoning using alcohol (X65)" with only a 3% (1-4%) increase in the highest density category.

The pattern for off-trade outlets for the two specific acute wholly attributable conditions was broadly similar to that for acute wholly attributable conditions as a whole.

With regard to the two specific chronic wholly attributable conditions, the overall directions of associations were similar to that for chronic wholly attributable conditions as a whole for on-trade and off-trade outlet categories. However, there were some differences in the magnitude of associations observed. The pubs, bars and nightclubs category had the strongest association with "Alcoholic liver disease (K70)", with a 30% (27-33%) increase in the admission rate ratio in the highest density category. Other on-trade outlets had the strongest association with "Mental and behavioural disorders due to alcohol (F10.1-F10.9)", with a 25% (22-27%) increase in the admission rate ratio in the highest density category.

Table 5. Associations between alcohol outlet density and hospital admissions attributable to alcohol for **BOTH SEXES COMBINED** at the LSOA level; England 2002/03 to 2013/14. Rate ratios (95% CI) for category by quartile of outlet density for people aged 15+ years are shown (outlet density within a 1-km radius of a postcode centroid, averaged for all postcodes within an LSOA).

	Rate ratios for alcohol outlet categories by quartile (1=lowest; 4=highest)			
Condition and Alcohol outlet category	1	2	3	4
Acute conditions wholly attributable to alcohol				
Pubs, bars, nightclubs	1	1.03 (1.02 - 1.04)	1.05 (1.04 - 1.06)	1.13 (1.11 - 1.15)
Restaurants	1	1.00 (0.99 - 1.01)	0.98 (0.97 - 0.99)	1.09 (1.07 - 1.10)
Other on-trade outlets	1	1.04 (1.02 - 1.05)	1.04 (1.02 - 1.05)	1.12 (1.10 - 1.14)
Supermarkets	1	0.99 (0.98 - 1.00)	0.98 (0.97 - 0.99)	1.03 (1.02 - 1.04)
Convenience stores	1	1.04 (1.03 - 1.05)	1.06 (1.05 - 1.07)	1.10 (1.09 - 1.12)
Other off-trade outlets	1	1.01 (0.99 - 1.02)	0.96 (0.95 - 0.98)	0.88 (0.87 - 0.89)
Chronic conditions wholly attributable to alcohol				
Pubs, bars, nightclubs	1	1.04 (1.02 - 1.05)	1.06 (1.05 - 1.08)	1.22 (1.21 - 1.24)
Restaurants	1	1.00 (0.99 - 1.01)	0.96 (0.95 - 0.97)	1.09 (1.07 - 1.11)
Other on-trade outlets	1	1.06 (1.04 - 1.07)	1.06 (1.05 - 1.08)	1.19 (1.17 - 1.21)
Supermarkets	1	0.98 (0.97 - 0.99)	0.97 (0.96 - 0.98)	1.04 (1.03 - 1.05)
Convenience stores	1	1.02 (1.01 - 1.03)	1.03 (1.02 - 1.04)	1.07 (1.06 - 1.09)
Other off-trade outlets	1	1.06 (1.04 - 1.07)	1.08 (1.07 - 1.10)	1.11 (1.09 - 1.12)
Acute conditions partially attributable to alcohol				
Pubs, bars, nightclubs	1	1.00 (1.00 - 1.01)	1.00 (0.99 - 1.01)	1.02 (1.01 - 1.03)
Restaurants	1	1.00 (0.99 - 1.00)	0.98 (0.98 - 0.99)	0.99 (0.98 - 1.00)
Other on-trade outlets	1	1.00 (0.99 - 1.01)	1.00 (1.00 - 1.01)	1.02 (1.01 - 1.03)
Supermarkets	1	1.00 (0.99 - 1.01)	1.00 (1.00 - 1.01)	1.02 (1.01 - 1.03)
Convenience stores	1	1.01 (1.00 - 1.02)	1.01 (1.00 - 1.02)	1.02 (1.01 - 1.03)
Other off-trade outlets	1	1.00 (0.99 - 1.01)	0.99 (0.98 - 1.00)	0.97 (0.96 - 0.98)
Chronic conditions				

partially attributable to alcohol				
Pubs, bars, nightclubs	1	1.01 (1.00 - 1.02)	1.03 (1.02 - 1.04)	1.06 (1.06 - 1.07)
Restaurants	1	0.99 (0.99 - 1.00)	0.99 (0.99 - 1.00)	1.01 (1.00 - 1.01)
Other on-trade outlets	1	1.00 (0.99 - 1.00)	0.98 (0.98 - 0.99)	1.00 (0.99 - 1.01)
Supermarkets	1	1.01 (1.00 - 1.01)	1.01 (1.00 - 1.02)	1.00 (1.00 - 1.01)
Convenience stores	1	0.99 (0.99 - 1.00)	1.00 (0.99 - 1.00)	0.98 (0.98 - 0.99)
Other off-trade outlets	1	0.98 (0.98 - 0.99)	0.99 (0.98 - 0.99)	1.01 (1.00 - 1.02)
Acute alcohol intoxication (F10.0)				
Pubs, bars, nightclubs	1	1.02 (1.00 - 1.04)	1.04 (1.02 - 1.06)	1.16 (1.13 - 1.19)
Restaurants	1	1.00 (0.98 - 1.02)	1.02 (1.00 - 1.04)	1.22 (1.19 - 1.25)
Other on-trade outlets	1	1.03 (1.01 - 1.05)	1.01 (0.99 - 1.03)	1.11 (1.08 - 1.13)
Supermarkets	1	0.98 (0.97 - 1.00)	0.97 (0.95 - 0.99)	1.01 (0.99 - 1.03)
Convenience stores	1	1.03 (1.01 - 1.05)	1.06 (1.04 - 1.08)	1.12 (1.10 - 1.14)
Other off-trade outlets	1	1.04 (1.02 - 1.06)	1.03 (1.01 - 1.05)	0.99 (0.96 - 1.01)
Intentional self-poisoning using alcohol (X65)				
Pubs, bars, nightclubs	1	1.04 (1.03 - 1.05)	1.07 (1.05 - 1.08)	1.13 (1.11 - 1.15)
Restaurants	1	1.00 (0.99 - 1.01)	0.96 (0.95 - 0.97)	1.03 (1.01 - 1.04)
Other on-trade outlets	1	1.04 (1.03 - 1.05)	1.04 (1.03 - 1.06)	1.11 (1.09 - 1.13)
Supermarkets	1	1.00 (0.99 - 1.01)	0.99 (0.98 - 1.00)	1.06 (1.05 - 1.07)
Convenience stores	1	1.05 (1.04 - 1.07)	1.07 (1.06 - 1.09)	1.11 (1.10 - 1.13)
Other off-trade outlets	1	0.98 (0.97 - 0.99)	0.92 (0.91 - 0.93)	0.81 (0.80 - 0.82)
Mental and behavioural disorders due to alcohol (F10.1-F10.9)				
Pubs, bars, nightclubs	1	1.01 (1.00 - 1.03)	1.04 (1.02 - 1.05)	1.18 (1.16 - 1.21)
Restaurants	1	0.99 (0.97 - 1.00)	0.96 (0.94 - 0.97)	1.12 (1.10 - 1.14)
Other on-trade outlets	1	1.06 (1.04 - 1.07)	1.08 (1.06 - 1.09)	1.25 (1.22 - 1.27)
Supermarkets	1	0.97 (0.96 - 0.98)	0.98 (0.97 - 1.00)	1.05 (1.04 - 1.07)
Convenience stores	1	1.03 (1.02 - 1.05)	1.04 (1.02 - 1.05)	1.09 (1.07 - 1.10)
Other off-trade outlets	1	1.07 (1.05 - 1.08)	1.09 (1.07 - 1.11)	1.07 (1.06 - 1.09)
Alcoholic liver				

disease (K70)				
Pubs, bars, nightclubs	1	1.05 (1.04 - 1.07)	1.10 (1.08 - 1.12)	1.30 (1.27 - 1.33)
Restaurants	1	1.02 (1.01 - 1.04)	0.96 (0.95 - 0.98)	1.03 (1.01 - 1.05)
Other on-trade outlets	1	1.06 (1.04 - 1.08)	1.03 (1.02 - 1.06)	1.13 (1.10 - 1.15)
Supermarkets	1	0.99 (0.98 - 1.01)	0.96 (0.95 - 0.98)	1.03 (1.01 - 1.04)
Convenience stores	1	1.01 (1.00 - 1.03)	1.02 (1.00 - 1.03)	1.06 (1.04 - 1.08)
Other off-trade outlets	1	1.04 (1.02 - 1.05)	1.06 (1.04 - 1.08)	1.15 (1.12 - 1.17)

Variation in associations between men and women

The results for men and women are presented in Tables 6 and 7 respectively.

The overall patterns of association between outlet density categories and the various outcomes in men and women were generally quite consistent. However, there were a few differences for three of the outlet categories in relation to some outcomes.

The main difference in the strength of association was for the other off-trade outlets category in relation to chronic conditions wholly attributable to alcohol, where the association in men was stronger than that for women. For men in the highest density category, the admission rate ratio increased by 15% (12-17%), whilst the equivalent increase for women was only 1% (-1 to 4%).

This pattern was reflected in the two specific chronic wholly attributable conditions. With regard to "Mental and behavioural disorders due to alcohol", the increase in the highest density category for other off-trade outlets was 11% (9-13%) for men but -1% (-4 to 2%) for women. Similarly, for "Alcoholic liver disease", the increase in the highest density category was 19% (16-22%) for men but 6% (2-10%) for women.

There were also some differences in relation to pubs, bars and nightclubs, with stronger associations seen for men for two of the specific conditions. For "Acute alcohol intoxication", the increase in the highest density category was 18% (14-22%) for men but 11% (7-16%) for women. For "Mental and behavioural disorders due to alcohol", the increase in the highest density category was 20% (17-23%) for men but 14% (11-18%) for women.

In addition, there were also some minor differences in relation to supermarkets and wholly attributable chronic conditions, where the strength of association by gender was reversed, with marginally stronger associations for women than men. The increase in the highest density category was 2% (1-4%) for men but higher, at 7% (5-9%), for women.

This was reflected in the "Mental and behavioural disorders due to alcohol" outcome, where the increase was 4% (2-6%) for men but again, higher at 9% (7-12%) for women. It was also reflected to a lesser extent for "Alcoholic liver disease", where the increase in the highest density category was 1% (-1 to 4%) for men but 5% (2-8%) for women.

Table 6. Associations between alcohol outlet density and hospital admissions attributable to alcohol for **MEN** at the LSOA level; England 2002/03 to 2013/14. Rate ratios (95% CI) for category by quartile of outlet density for men aged 15+ years are shown (outlet density within a 1-km radius of a postcode centroid, averaged for all postcodes within an LSOA).

	Rate ratios for alcohol outlet categories by quartile (1=lowest; 4=highest)			
Condition and Alcohol outlet category	1	2	3	4
Acute conditions wholly attributable to alcohol				
Pubs, bars, nightclubs	1	1.04 (1.03 - 1.06)	1.07 (1.05 - 1.08)	1.15 (1.13 - 1.18)
Restaurants	1	0.99 (0.98 - 1.01)	0.98 (0.96 - 0.99)	1.08 (1.06 - 1.10)
Other on-trade outlets	1	1.03 (1.01 - 1.04)	1.03 (1.02 - 1.05)	1.12 (1.10 - 1.15)
Supermarkets	1	0.98 (0.97 - 1.00)	0.96 (0.95 - 0.98)	1.02 (1.01 - 1.04)
Convenience stores	1	1.03 (1.02 - 1.05)	1.06 (1.04 - 1.07)	1.09 (1.08 - 1.11)
Other off-trade outlets	1	1.02 (1.00 - 1.03)	0.99 (0.97 - 1.00)	0.91 (0.89 - 0.93)
Chronic conditions wholly attributable to alcohol				
Pubs, bars, nightclubs	1	1.04 (1.02 - 1.05)	1.07 (1.05 - 1.09)	1.23 (1.21 - 1.26)
Restaurants	1	1.00 (0.99 - 1.02)	0.95 (0.94 - 0.97)	1.09 (1.07 - 1.11)
Other on-trade outlets	1	1.06 (1.04 - 1.08)	1.06 (1.04 - 1.08)	1.20 (1.18 - 1.23)
Supermarkets	1	0.98 (0.97 - 0.99)	0.98 (0.96 - 0.99)	1.02 (1.01 - 1.04)
Convenience stores	1	1.02 (1.00 - 1.03)	1.02 (1.01 - 1.04)	1.07 (1.05 - 1.09)
Other off-trade outlets	1	1.07 (1.05 - 1.09)	1.10 (1.08 - 1.12)	1.15 (1.12 - 1.17)
Acute conditions partially attributable to alcohol				
Pubs, bars, nightclubs	1	1.00 (1.00 - 1.01)	1.01 (1.00 - 1.02)	1.03 (1.01 - 1.04)
Restaurants	1	1.00 (0.99 - 1.01)	0.98 (0.97 - 0.99)	0.98 (0.96 - 0.99)
Other on-trade outlets	1	1.00 (0.99 - 1.01)	1.00 (0.99 - 1.01)	1.01 (1.00 - 1.03)
Supermarkets	1	1.00 (0.99 - 1.01)	1.00 (0.99 - 1.01)	1.02 (1.01 - 1.03)
Convenience stores	1	1.01 (1.00 - 1.02)	1.01 (1.00 - 1.02)	1.01 (1.00 - 1.02)
Other off-trade outlets	1	1.00 (0.99 - 1.01)	0.99 (0.98 - 1.00)	0.96 (0.95 - 0.97)
Chronic conditions				

partially attributable to alcohol				
Pubs, bars, nightclubs	1	1.01 (1.00 - 1.02)	1.03 (1.02 - 1.04)	1.08 (1.07 - 1.10)
Restaurants	1	0.99 (0.99 - 1.00)	0.99 (0.98 - 1.00)	1.00 (0.99 - 1.01)
Other on-trade outlets	1	1.00 (0.99 - 1.01)	0.98 (0.97 - 0.99)	0.99 (0.98 - 1.00)
Supermarkets	1	1.01 (1.00 - 1.02)	1.01 (1.00 - 1.02)	1.01 (1.00 - 1.02)
Convenience stores	1	0.99 (0.99 - 1.00)	1.00 (0.99 - 1.01)	0.99 (0.98 - 1.00)
Other off-trade outlets	1	0.98 (0.97 - 0.99)	0.99 (0.98 - 1.00)	1.01 (1.00 - 1.02)
Acute alcohol intoxication (F10.0)				
Pubs, bars, nightclubs	1	1.03 (1.00 - 1.05)	1.05 (1.02 - 1.08)	1.18 (1.14 - 1.22)
Restaurants	1	0.99 (0.97 - 1.01)	1.01 (0.98 - 1.03)	1.20 (1.17 - 1.24)
Other on-trade outlets	1	1.01 (0.98 - 1.03)	1.00 (0.98 - 1.03)	1.10 (1.07 - 1.13)
Supermarkets	1	0.98 (0.96 - 1.00)	0.97 (0.95 - 0.99)	1.02 (0.99 - 1.04)
Convenience stores	1	1.04 (1.01 - 1.06)	1.05 (1.03 - 1.07)	1.12 (1.09 - 1.15)
Other off-trade outlets	1	1.05 (1.02 - 1.08)	1.04 (1.02 - 1.07)	1.02 (0.99 - 1.05)
Intentional self-poisoning using alcohol (X65)				
Pubs, bars, nightclubs	1	1.06 (1.04 - 1.08)	1.08 (1.06 - 1.11)	1.15 (1.12 - 1.18)
Restaurants	1	0.99 (0.98 - 1.01)	0.96 (0.94 - 0.98)	1.01 (0.98 - 1.03)
Other on-trade outlets	1	1.04 (1.02 - 1.06)	1.05 (1.02 - 1.07)	1.12 (1.09 - 1.15)
Supermarkets	1	0.98 (0.97 - 1.00)	0.98 (0.96 - 1.00)	1.05 (1.03 - 1.07)
Convenience stores	1	1.05 (1.03 - 1.07)	1.07 (1.05 - 1.09)	1.09 (1.06 - 1.11)
Other off-trade outlets	1	0.99 (0.97 - 1.01)	0.93 (0.91 - 0.95)	0.81 (0.79 - 0.83)
Mental and behavioural disorders due to alcohol (F10.1-F10.9)				
Pubs, bars, nightclubs	1	1.02 (1.00 - 1.04)	1.05 (1.03 - 1.08)	1.20 (1.17 - 1.23)
Restaurants	1	1.00 (0.98 - 1.01)	0.95 (0.94 - 0.97)	1.12 (1.10 - 1.15)
Other on-trade outlets	1	1.06 (1.04 - 1.08)	1.08 (1.06 - 1.10)	1.26 (1.23 - 1.29)
Supermarkets	1	0.97 (0.95 - 0.98)	0.98 (0.97 - 1.00)	1.04 (1.02 - 1.06)
Convenience stores	1	1.04 (1.02 - 1.05)	1.04 (1.02 - 1.06)	1.09 (1.07 - 1.11)
Other off-trade outlets	1	1.08 (1.06 - 1.10)	1.11 (1.09 - 1.13)	1.11 (1.09 - 1.13)
Alcoholic liver				

disease (K70)				
Pubs, bars, nightclubs	1	1.06 (1.04 - 1.08)	1.11 (1.09 - 1.14)	1.31 (1.27 - 1.35)
Restaurants	1	1.02 (1.00 - 1.04)	0.96 (0.94 - 0.98)	1.02 (1.00 - 1.05)
Other on-trade outlets	1	1.06 (1.04 - 1.09)	1.04 (1.01 - 1.06)	1.14 (1.10 - 1.17)
Supermarkets	1	1.00 (0.98 - 1.02)	0.97 (0.95 - 0.99)	1.01 (0.99 - 1.04)
Convenience stores	1	1.00 (0.98 - 1.02)	1.01 (0.99 - 1.03)	1.04 (1.02 - 1.07)
Other off-trade outlets	1	1.05 (1.03 - 1.07)	1.07 (1.04 - 1.09)	1.19 (1.16 - 1.22)

Table 7. Associations between alcohol outlet density and hospital admissions attributable to alcohol for **WOMEN** at the LSOA level; England 2002/03 to 2013/14. Rate ratios (95% CI) for category by quartile of outlet density for women aged 15+ years are shown (outlet density within a 1-km radius of a postcode centroid, averaged for all postcodes within an LSOA).

	Rate ratios for alcohol outlet categories by quartile (1=lowest; 4=highest)			
Condition and Alcohol outlet category	1	2	3	4
Acute conditions wholly attributable to alcohol				
Pubs, bars, nightclubs	1	1.02 (1.00 - 1.03)	1.04 (1.02 - 1.06)	1.10 (1.07 - 1.12)
Restaurants	1	1.01 (1.00 - 1.02)	0.98 (0.96 - 0.99)	1.09 (1.07 - 1.11)
Other on-trade outlets	1	1.04 (1.03 - 1.06)	1.04 (1.02 - 1.06)	1.11 (1.09 - 1.14)
Supermarkets	1	1.00 (0.99 - 1.01)	0.99 (0.98 - 1.00)	1.04 (1.03 - 1.06)
Convenience stores	1	1.05 (1.03 - 1.06)	1.07 (1.05 - 1.09)	1.11 (1.10 - 1.13)
Other off-trade outlets	1	1.00 (0.98 - 1.01)	0.95 (0.93 - 0.96)	0.86 (0.84 - 0.87)
Chronic conditions wholly attributable to alcohol				
Pubs, bars, nightclubs	1	1.03 (1.01 - 1.05)	1.05 (1.02 - 1.07)	1.21 (1.18 - 1.24)
Restaurants	1	0.99 (0.98 - 1.01)	0.97 (0.95 - 0.99)	1.09 (1.06 - 1.11)
Other on-trade outlets	1	1.05 (1.03 - 1.07)	1.06 (1.03 - 1.08)	1.16 (1.13 - 1.19)
Supermarkets	1	0.97 (0.96 - 0.99)	0.97 (0.95 - 0.98)	1.07 (1.05 - 1.09)
Convenience stores	1	1.03 (1.01 - 1.05)	1.04 (1.02 - 1.06)	1.08 (1.06 - 1.10)
Other off-trade outlets	1	1.03 (1.01 - 1.05)	1.05 (1.03 - 1.08)	1.01 (0.99 - 1.04)
Acute conditions partially attributable to alcohol				
Pubs, bars, nightclubs	1	1.00 (0.98 - 1.01)	0.99 (0.97 - 1.01)	1.01 (0.99 - 1.03)
Restaurants	1	1.00 (0.98 - 1.01)	0.99 (0.97 - 1.00)	1.02 (1.00 - 1.04)
Other on-trade outlets	1	1.00 (0.99 - 1.02)	1.00 (0.99 - 1.02)	1.02 (1.00 - 1.04)
Supermarkets	1	1.01 (0.99 - 1.02)	1.01 (1.00 - 1.02)	1.03 (1.01 - 1.04)
Convenience stores	1	1.01 (0.99 - 1.02)	1.01 (1.00 - 1.03)	1.03 (1.01 - 1.04)
Other off-trade outlets	1	1.01 (0.99 - 1.02)	0.99 (0.98 - 1.01)	0.98 (0.96 - 1.00)
Chronic conditions				

partially attributable to alcohol				
Pubs, bars, nightclubs	1	1.01 (1.00 - 1.02)	1.03 (1.02 - 1.04)	1.04 (1.03 - 1.05)
Restaurants	1	0.99 (0.99 - 1.00)	0.99 (0.99 - 1.00)	1.01 (1.00 - 1.02)
Other on-trade outlets	1	1.00 (0.99 - 1.01)	0.99 (0.98 - 1.00)	1.01 (1.00 - 1.02)
Supermarkets	1	1.00 (1.00 - 1.01)	1.01 (1.00 - 1.02)	0.99 (0.98 - 1.00)
Convenience stores	1	0.99 (0.98 - 1.00)	0.99 (0.98 - 1.00)	0.97 (0.96 - 0.98)
Other off-trade outlets	1	0.99 (0.98 - 1.00)	0.99 (0.98 - 1.00)	1.00 (0.99 - 1.01)
Acute alcohol intoxication (F10.0)				
Pubs, bars, nightclubs	1	1.00 (0.97 - 1.03)	1.02 (0.98 - 1.05)	1.11 (1.07 - 1.16)
Restaurants	1	1.02 (0.99 - 1.05)	1.04 (1.01 - 1.07)	1.24 (1.19 - 1.28)
Other on-trade outlets	1	1.06 (1.03 - 1.09)	1.03 (0.99 - 1.06)	1.11 (1.07 - 1.16)
Supermarkets	1	0.99 (0.96 - 1.02)	0.98 (0.95 - 1.00)	1.01 (0.98 - 1.04)
Convenience stores	1	1.03 (1.00 - 1.06)	1.07 (1.04 - 1.10)	1.11 (1.08 - 1.15)
Other off-trade outlets	1	1.03 (1.00 - 1.07)	1.01 (0.97 - 1.04)	0.94 (0.90 - 0.97)
Intentional self-poisoning using alcohol (X65)				
Pubs, bars, nightclubs	1	1.03 (1.01 - 1.05)	1.05 (1.03 - 1.07)	1.11 (1.08 - 1.13)
Restaurants	1	1.00 (0.99 - 1.02)	0.96 (0.94 - 0.97)	1.04 (1.01 - 1.06)
Other on-trade outlets	1	1.04 (1.02 - 1.06)	1.04 (1.02 - 1.06)	1.10 (1.07 - 1.12)
Supermarkets	1	1.01 (0.99 - 1.03)	1.00 (0.99 - 1.02)	1.07 (1.05 - 1.08)
Convenience stores	1	1.06 (1.04 - 1.07)	1.08 (1.06 - 1.10)	1.13 (1.11 - 1.16)
Other off-trade outlets	1	0.98 (0.96 - 0.99)	0.91 (0.90 - 0.93)	0.81 (0.79 - 0.83)
Mental and behavioural disorders due to alcohol (F10.1-F10.9)				
Pubs, bars, nightclubs	1	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.03)	1.14 (1.11 - 1.18)
Restaurants	1	0.96 (0.94 - 0.98)	0.96 (0.94 - 0.99)	1.10 (1.07 - 1.14)
Other on-trade outlets	1	1.05 (1.02 - 1.07)	1.08 (1.05 - 1.11)	1.22 (1.18 - 1.26)
Supermarkets	1	0.98 (0.95 - 1.00)	0.99 (0.96 - 1.01)	1.09 (1.07 - 1.12)
Convenience stores	1	1.02 (1.00 - 1.05)	1.04 (1.01 - 1.06)	1.07 (1.05 - 1.10)
Other off-trade outlets	1	1.05 (1.02 - 1.07)	1.06 (1.03 - 1.09)	0.99 (0.96 - 1.02)
Alcoholic liver				

disease (K70)				
Pubs, bars, nightclubs	1	1.04 (1.01 - 1.07)	1.08 (1.05 - 1.12)	1.27 (1.22 - 1.32)
Restaurants	1	1.02 (0.99 - 1.04)	0.97 (0.94 - 1.00)	1.04 (1.00 - 1.08)
Other on-trade outlets	1	1.05 (1.02 - 1.08)	1.03 (1.00 - 1.07)	1.10 (1.06 - 1.15)
Supermarkets	1	0.97 (0.94 - 0.99)	0.95 (0.93 - 0.98)	1.05 (1.02 - 1.08)
Convenience stores	1	1.04 (1.01 - 1.07)	1.04 (1.01 - 1.07)	1.09 (1.06 - 1.12)
Other off-trade outlets	1	1.01 (0.98 - 1.04)	1.05 (1.02 - 1.08)	1.06 (1.02 - 1.10)

Variation in associations by age

We examined if age modified the associations between alcohol outlet categories and admissions using the two outcome categories which captured the main associations – (i) acute conditions wholly attributable to alcohol, and (ii) chronic conditions wholly attributable to alcohol.

Four broad age bands were used: 15-24; 25-44; 45-64 and 65+ years (with indirect standardisation within age bands using 5-year bands). Our prior hypothesis was that acute effects would tend to be stronger in younger people while chronic effects would be stronger in older people. The results for the acute and chronic conditions are presented in Tables 8 and 9 respectively.

For acute wholly attributable conditions, there was a general trend of stronger association with increasing age in the highest on-trade density categories. This was seen for all three on-trade categories.

For pubs, bars and nightclubs, the increase in admission rate ratio in the highest density category progressively rose from 7% (4-10%) in the 15-24 age group to 26% (18-34%) in the 65+ age group.

For restaurants, the increase in admission rate in the highest density category progressively rose from 1% (-2 to 3%) in the 15-24 age group to 31% (24-39%) in the 65+ age group.

For other on-trade outlets, the increase in admission rate in the highest density category progressively rose from 3% (1-6%) in the 15-24 age group to 17% (10-25%) in the 65+ age group.

There was a similar but less consistent trend for chronic wholly attributable conditions in relation to all three on-trade outlet categories.

For off-trade outlets, however, there were no consistent trends regarding effect modification by age for either acute or chronic wholly attributable conditions.

Overall, there was no evidence to support the hypothesis that acute effects would be stronger in younger people whilst chronic effects would be stronger in older people.

Table 8. Effect of **AGE** on associations between alcohol outlet density and hospital admissions for **acute** conditions wholly attributable to alcohol, England 2002/03 to 2013/14. Rate ratios (95% CI) for category by quartile of outlet density for men and women combined are shown (outlet density within a 1-km radius of a postcode centroid, averaged for all postcodes within an LSOA).

	Rate ratios for alcohol outlet categories by quartile (1=lowest; 4=highest)			
Alcohol outlet category and age band (years)	1	2	3	4
Pubs, bars, nightclubs				
15-24	1	1.03 (1.01 - 1.05)	1.05 (1.03 - 1.08)	1.07 (1.04 - 1.10)
25-44	1	1.04 (1.02 - 1.05)	1.05 (1.03 - 1.07)	1.11 (1.09 - 1.14)
45-64	1	1.01 (0.99 - 1.03)	1.05 (1.03 - 1.07)	1.21 (1.18 - 1.24)
65+	1	1.09 (1.04 - 1.15)	1.06 (1.00 - 1.12)	1.26 (1.18 - 1.34)
Restaurants				
15-24	1	1.00 (0.99 - 1.02)	0.97 (0.95 - 0.99)	1.01 (0.98 - 1.03)
25-44	1	1.00 (0.98 - 1.01)	0.97 (0.95 - 0.98)	1.06 (1.04 - 1.08)
45-64	1	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.01)	1.20 (1.17 - 1.23)
65+	1	1.04 (1.00 - 1.09)	1.03 (0.99 - 1.08)	1.31 (1.24 - 1.39)
Other on-trade outlets				
15-24	1	1.04 (1.02 - 1.06)	1.02 (1.00 - 1.05)	1.03 (1.01 - 1.06)
25-44	1	1.03 (1.02 - 1.05)	1.04 (1.02 - 1.05)	1.13 (1.11 - 1.15)
45-64	1	1.03 (1.01 - 1.05)	1.03 (1.01 - 1.06)	1.16 (1.13 - 1.19)
65+	1	0.99 (0.94 - 1.04)	1.02 (0.97 - 1.08)	1.17 (1.10 - 1.25)
Supermarkets				
15-24	1	0.99 (0.98 - 1.01)	0.98 (0.96 - 1.00)	1.03 (1.01 - 1.05)
25-44	1	0.98 (0.96 - 0.99)	0.96 (0.95 - 0.98)	1.03 (1.01 - 1.04)
45-64	1	1.00 (0.99 - 1.02)	0.99 (0.98 - 1.01)	1.05 (1.03 - 1.07)
65+	1	0.98 (0.94 - 1.02)	0.96 (0.92 - 1.00)	0.98 (0.93 - 1.02)
Convenience stores				
15-24	1	1.02 (1.00 - 1.04)	1.07 (1.05 - 1.09)	1.06 (1.04 - 1.09)
25-44	1	1.05 (1.03 - 1.06)	1.06 (1.05 - 1.08)	1.12 (1.10 - 1.14)
45-64	1	1.04 (1.02 - 1.06)	1.06 (1.04 - 1.08)	1.11 (1.09 - 1.14)
65+	1	1.02 (0.97 - 1.07)	1.01 (0.97 - 1.06)	1.13 (1.07 - 1.18)
Other off-trade outlets				
15-24	1	0.99 (0.97 - 1.01)	0.95 (0.93 - 0.97)	0.82 (0.80 - 0.84)
25-44	1	1.00 (0.99 - 1.02)	0.94 (0.93 - 0.96)	0.85 (0.84 - 0.87)
45-64	1	1.03 (1.01 - 1.05)	1.01 (0.98 - 1.03)	0.99 (0.96 - 1.01)
65+	1	1.00 (0.96 - 1.05)	1.04 (0.99 - 1.09)	1.09 (1.03 - 1.16)

Table 9. Effect of **AGE** on associations between alcohol outlet density and hospital admissions for **chronic** conditions wholly attributable to alcohol, England 2002/03 to 2013/14. Rate ratios (95% CI) for category by quartile of outlet density for men and women combined are shown (outlet density within a 1-km radius of a postcode centroid, averaged for all postcodes within an LSOA).

	Rate ratios for alcohol outlet categories by quartile (1=lowest; 4=highest)			
Alcohol outlet category and age band (years)	1	2	3	4
Pubs, bars, nightclubs				
15-24	1	1.08 (1.01 - 1.15)	1.12 (1.05 - 1.21)	1.17 (1.07 - 1.28)
25-44	1	1.01 (0.99 - 1.03)	1.06 (1.04 - 1.07)	1.18 (1.16 - 1.21)
45-64	1	1.06 (1.04 - 1.07)	1.07 (1.06 - 1.09)	1.28 (1.26 - 1.30)
65+	1	1.02 (0.99 - 1.05)	1.01 (0.98 - 1.05)	1.24 (1.19 - 1.29)
Restaurants				
15-24	1	1.06 (1.00 - 1.12)	1.01 (0.95 - 1.08)	1.03 (0.95 - 1.11)
25-44	1	1.00 (0.99 - 1.02)	0.95 (0.93 - 0.96)	1.06 (1.04 - 1.08)
45-64	1	0.98 (0.97 - 1.00)	0.95 (0.94 - 0.96)	1.11 (1.09 - 1.13)
65+	1	1.03 (1.00 - 1.06)	1.00 (0.97 - 1.03)	1.11 (1.07 - 1.16)
Other on-trade outlets				
15-24	1	1.04 (0.97 - 1.11)	1.05 (0.98 - 1.13)	1.00 (0.92 - 1.09)
25-44	1	1.04 (1.03 - 1.06)	1.05 (1.03 - 1.07)	1.18 (1.16 - 1.21)
45-64	1	1.06 (1.05 - 1.08)	1.06 (1.04 - 1.08)	1.20 (1.18 - 1.22)
65+	1	1.08 (1.05 - 1.12)	1.11 (1.07 - 1.15)	1.24 (1.18 - 1.29)
Supermarkets				
15-24	1	0.94 (0.89 - 1.00)	0.99 (0.94 - 1.05)	1.04 (0.98 - 1.10)
25-44	1	0.94 (0.93 - 0.96)	0.94 (0.93 - 0.96)	1.02 (1.00 - 1.03)
45-64	1	1.00 (0.99 - 1.02)	0.99 (0.98 - 1.01)	1.06 (1.05 - 1.08)
65+	1	1.01 (0.98 - 1.03)	1.01 (0.98 - 1.04)	0.99 (0.96 - 1.02)
Convenience stores				
15-24	1	1.00 (0.94 - 1.07)	1.05 (0.99 - 1.11)	1.02 (0.95 - 1.09)
25-44	1	1.01 (1.00 - 1.03)	1.04 (1.03 - 1.06)	1.08 (1.06 - 1.09)
45-64	1	1.03 (1.02 - 1.05)	1.03 (1.01 - 1.04)	1.09 (1.07 - 1.10)
65+	1	1.00 (0.97 - 1.03)	0.99 (0.96 - 1.02)	1.06 (1.03 - 1.10)
Other off-trade outlets				
15-24	1	1.00 (0.93 - 1.07)	0.96 (0.90 - 1.03)	0.90 (0.84 - 0.97)
25-44	1	1.10 (1.08 - 1.12)	1.12 (1.10 - 1.14)	1.10 (1.07 - 1.12)
45-64	1	1.04 (1.03 - 1.06)	1.07 (1.06 - 1.09)	1.15 (1.13 - 1.17)
65+	1	0.98 (0.95 - 1.01)	1.01 (0.98 - 1.04)	1.08 (1.04 - 1.12)

Variation in associations by socioeconomic deprivation

We examined if associations between outlet density and admissions were modified by socioeconomic deprivation at the area level. Our prior hypothesis was that effect sizes would increase with increasing levels of socioeconomic deprivation.

These patterns were examined for acute and chronic conditions wholly attributable to alcohol and the results are presented in Tables 10 and 11 respectively.

For acute wholly attributable conditions, effects were greater in some of the higher deprivation categories. However, there were no consistent patterns for any of the six outlet categories to indicate that the effects of outlet density progressively increased with increasing socioeconomic deprivation at the area level.

Similarly, for chronic wholly attributable conditions, there was no evidence of any consistent pattern of increasing effect size with increasing levels of deprivation for any of the outlet categories.

Variation in associations by urban-rural status

We planned to examine if associations between outlet density and admissions were different in urban and rural areas. However, we could not adequately assess effects in the rural categories because of the very small numbers of LSOAs in the highest density categories. For example, there were only two rural LSOAs in the highest density category for pubs, bars and nightclubs.

We therefore just examined associations restricted to LSOAs in the urban category. Rate ratios for urban areas were very similar to rate ratios for all urban and rural areas combined (presented previously in Table 5) and are not included in this report.

Lagged effects, distance radii and spatial random effects

The results of these more technical aspects of the analysis are presented in the Technical Appendix.

Table 10. Effect of **SOCIOECONOMIC DEPRIVATION** on associations between alcohol outlet density and hospital admissions for **acute** conditions wholly attributable to alcohol, England 2002/03 to 2013/14. Rate ratios (95% CI) for category by quartile of outlet density for men and women combined are shown (outlet density within a 1-km radius of a postcode centroid, averaged for all postcodes within an LSOA).

	Rate ratios for alcohol outlet categories by quartile (1=lowest; 4=highest)			
Alcohol outlet category and deprivation category	1	2	3	4
Pubs, bars, nightclubs				
1 (most deprived)	1	1.04 (1.02 - 1.06)	1.02 (1.00 - 1.05)	1.06 (1.03 - 1.09)
2	1	1.06 (1.03 - 1.09)	1.11 (1.08 - 1.14)	1.23 (1.19 - 1.27)
3	1	0.99 (0.97 - 1.02)	1.04 (1.01 - 1.07)	1.15 (1.11 - 1.20)
4	1	1.06 (1.03 - 1.09)	1.09 (1.06 - 1.13)	1.24 (1.19 - 1.29)
5 (least deprived)	1	1.00 (0.98 - 1.03)	1.04 (1.01 - 1.07)	1.02 (0.97 - 1.08)
Restaurants				
1 (most deprived)	1	1.05 (1.03 - 1.07)	1.03 (1.01 - 1.05)	1.21 (1.18 - 1.24)
2	1	0.97 (0.95 - 0.99)	0.95 (0.93 - 0.97)	1.02 (0.99 - 1.05)
3	1	0.98 (0.96 - 1.01)	0.95 (0.93 - 0.97)	1.03 (0.99 - 1.06)
4	1	1.02 (1.00 - 1.05)	1.00 (0.97 - 1.03)	1.01 (0.97 - 1.05)
5 (least deprived)	1	1.01 (0.99 - 1.04)	1.01 (0.98 - 1.04)	1.02 (0.98 - 1.07)
Other on-trade outlets				
1 (most deprived)	1	0.96 (0.94 - 0.99)	0.94 (0.92 - 0.96)	0.99 (0.96 - 1.02)
2	1	1.05 (1.02 - 1.07)	1.03 (1.00 - 1.06)	1.13 (1.09 - 1.16)
3	1	1.07 (1.04 - 1.09)	1.09 (1.05 - 1.12)	1.21 (1.17 - 1.25)
4	1	1.04 (1.02 - 1.07)	1.10 (1.06 - 1.13)	1.21 (1.17 - 1.26)
5 (least deprived)	1	1.02 (1.00 - 1.05)	1.08 (1.05 - 1.12)	1.13 (1.08 - 1.18)
Supermarkets				
1 (most deprived)	1	0.94 (0.92 - 0.96)	0.90 (0.88 - 0.92)	0.97 (0.95 - 0.99)
2	1	1.00 (0.97 - 1.02)	0.99 (0.97 - 1.01)	1.04 (1.02 - 1.06)
3	1	0.98 (0.96 - 1.01)	1.00 (0.98 - 1.03)	1.03 (1.00 - 1.05)
4	1	1.02 (0.99 - 1.04)	1.01 (0.99 - 1.04)	1.06 (1.03 - 1.09)
5 (least deprived)	1	1.03 (1.00 - 1.05)	1.04 (1.02 - 1.07)	1.09 (1.05 - 1.13)
Convenience stores				
1 (most deprived)	1	1.08 (1.06 - 1.11)	1.10 (1.08 - 1.13)	1.17 (1.14 - 1.20)
2	1	1.01 (0.99 - 1.04)	1.03 (1.01 - 1.05)	1.07 (1.04 - 1.10)
3	1	1.01 (0.99 - 1.04)	1.05 (1.02 - 1.07)	1.04 (1.01 - 1.07)
4	1	1.01 (0.99 - 1.04)	0.99 (0.96 - 1.01)	0.98 (0.95 - 1.02)
5 (least deprived)	1	1.03 (1.00 - 1.05)	1.02 (0.99 - 1.05)	1.04 (1.01 - 1.08)
Other off-trade outlets				

1 (most deprived)	1	0.97 (0.94 - 0.99)	0.89 (0.87 - 0.92)	0.80 (0.78 - 0.82)
2	1	0.97 (0.94 - 0.99)	0.94 (0.92 - 0.97)	0.88 (0.86 - 0.91)
3	1	1.04 (1.02 - 1.07)	1.02 (0.99 - 1.05)	0.98 (0.95 - 1.01)
4	1	1.04 (1.01 - 1.07)	1.01 (0.98 - 1.04)	1.02 (0.98 - 1.06)
5 (least deprived)	1	1.02 (1.00 - 1.05)	1.00 (0.97 - 1.03)	1.02 (0.97 - 1.08)

Table 11. Effect of **SOCIOECONOMIC DEPRIVATION** on associations between alcohol outlet density and hospital admissions for **chronic** conditions wholly attributable to alcohol, England 2002/03 to 2013/14. Rate ratios (95% CI) for category by quartile of outlet density for men and women combined are shown (outlet density within a 1-km radius of a postcode centroid, averaged for all postcodes within an LSOA).

	Rate ratios for alcohol outlet categories by quartile (1=lowest; 4=highest)			
Alcohol outlet category and deprivation category	1	2	3	4
Pubs, bars, nightclubs				
1 (most deprived)	1	1.01 (0.98 - 1.04)	1.01 (0.99 - 1.04)	1.18 (1.15 - 1.22)
2	1	1.04 (1.01 - 1.07)	1.06 (1.03 - 1.09)	1.24 (1.20 - 1.28)
3	1	1.01 (0.98 - 1.04)	1.05 (1.02 - 1.08)	1.25 (1.20 - 1.30)
4	1	1.05 (1.02 - 1.08)	1.12 (1.09 - 1.16)	1.22 (1.17 - 1.28)
5 (least deprived)	1	1.08 (1.05 - 1.10)	1.16 (1.12 - 1.20)	1.30 (1.24 - 1.38)
Restaurants				
1 (most deprived)	1	0.99 (0.97 - 1.01)	0.92 (0.90 - 0.94)	1.06 (1.03 - 1.08)
2	1	0.98 (0.95 - 1.00)	0.93 (0.90 - 0.95)	1.03 (1.00 - 1.06)
3	1	1.00 (0.97 - 1.02)	1.03 (1.00 - 1.06)	1.18 (1.14 - 1.22)
4	1	1.08 (1.05 - 1.10)	1.11 (1.07 - 1.14)	1.21 (1.16 - 1.25)
5 (least deprived)	1	1.06 (1.03 - 1.08)	1.01 (0.98 - 1.04)	1.09 (1.05 - 1.14)
Other on-trade outlets				
1 (most deprived)	1	1.00 (0.97 - 1.02)	1.00 (0.98 - 1.03)	1.13 (1.10 - 1.17)
2	1	1.04 (1.01 - 1.07)	1.03 (1.00 - 1.06)	1.17 (1.13 - 1.21)
3	1	1.08 (1.05 - 1.12)	1.11 (1.07 - 1.15)	1.22 (1.18 - 1.27)
4	1	1.07 (1.04 - 1.10)	1.09 (1.06 - 1.13)	1.23 (1.18 - 1.29)
5 (least deprived)	1	1.07 (1.05 - 1.10)	1.07 (1.04 - 1.11)	1.15 (1.09 - 1.21)
Supermarkets				
1 (most deprived)	1	0.95 (0.93 - 0.97)	0.95 (0.93 - 0.97)	1.04 (1.01 - 1.06)
2	1	1.00 (0.97 - 1.02)	0.99 (0.97 - 1.01)	1.05 (1.03 - 1.08)
3	1	0.96 (0.94 - 0.99)	0.97 (0.94 - 0.99)	0.97 (0.94 - 1.00)
4	1	1.03 (1.00 - 1.05)	1.01 (0.98 - 1.03)	1.06 (1.02 - 1.09)
5 (least deprived)	1	0.93 (0.91 - 0.95)	0.94 (0.91 - 0.96)	0.92 (0.89 - 0.96)
Convenience stores				
1 (most deprived)	1	1.03 (1.01 - 1.06)	1.03 (1.01 - 1.06)	1.08 (1.06 - 1.11)
2	1	1.04 (1.01 - 1.06)	1.05 (1.03 - 1.08)	1.10 (1.07 - 1.13)
3	1	0.99 (0.96 - 1.02)	0.99 (0.97 - 1.02)	1.03 (1.00 - 1.06)
4	1	1.00 (0.98 - 1.03)	1.00 (0.97 - 1.03)	1.06 (1.03 - 1.10)
5 (least deprived)	1	1.01 (0.98 - 1.03)	1.00 (0.97 - 1.03)	1.04 (1.00 - 1.08)
Other off-trade outlets				

1 (most deprived)	1	1.06 (1.03 - 1.10)	1.12 (1.09 - 1.15)	1.09 (1.06 - 1.13)
2	1	1.04 (1.01 - 1.07)	1.08 (1.05 - 1.11)	1.11 (1.07 - 1.14)
3	1	1.10 (1.07 - 1.13)	1.08 (1.05 - 1.11)	1.18 (1.15 - 1.22)
4	1	0.99 (0.97 - 1.02)	0.97 (0.94 - 1.00)	1.07 (1.03 - 1.11)
5 (least deprived)	1	1.05 (1.03 - 1.08)	1.06 (1.02 - 1.09)	1.23 (1.17 - 1.29)

DISCUSSION

Summary

We examined associations at the LSOA level between the densities of six categories of alcohol outlets and hospital admissions due to acute or chronic conditions wholly or partially attributable to alcohol consumption. We used outlet density within a 1-km radius of postcode centroids, averaged for all postcodes within an LSOA. After adjustment for a range of potential confounders, we found several positive associations, with higher admission rate ratios mainly observed in the highest density categories by quartile.

With regard to on-trade outlets, pubs, bars and nightclubs were associated with higher admissions of both acute and chronic conditions wholly attributable to alcohol, with increases in rate ratios of 13% (11-15%) and 22% (21-24%) in the highest, relative to the lowest, density category for acute and chronic conditions respectively. Restaurants were also associated with higher admissions of both acute and chronic conditions wholly attributable to alcohol, with increases of 9% (7-10%) and 9% (7-11%) respectively in the highest density category. Other on-trade outlets were also associated with higher admissions of both acute and chronic conditions wholly attributable to alcohol, with increases of 12% (10-14%) and 19% (17-21%) respectively in the highest density category.

With regard to off-trade outlets, convenience stores were associated with higher admissions of both acute and chronic conditions wholly attributable to alcohol, with increases of 10% (9-12%) and 7% (6-9%) respectively in the highest density category. Supermarkets, however, were only associated with a modest increase in admissions of acute and chronic conditions wholly attributable to alcohol, with increases of 3% (2-4%) and 4% (3-5%) respectively in the highest density category. Other off-trade outlets were only associated with an increase in admissions for chronic conditions wholly attributable to alcohol, with an increase of 11% (9-12%) in the highest density category.

Specific conditions wholly attributable to alcohol (acute alcohol intoxication; intentional self-poisoning using alcohol; mental and behavioural disorders due to alcohol; alcoholic liver disease) generally displayed admission patterns broadly consistent with those described above. For conditions partially attributable to alcohol, however, there were generally no strong patterns of association with the outlet categories.

The strength of associations for on-trade outlets generally increased with increasing age but there were no consistent trends with age for off-trade outlets. Patterns of association were generally similar in men and women, apart from a few differences. There were no consistent patterns to indicate that associations increased with increasing levels of socioeconomic deprivation. There was also no evidence of lagged effects of outlet density on admissions. Use of radii larger than 1-km to calculate outlet density diminished or abolished positive associations. Adjusting for residual spatial autocorrelation did not substantially alter the general pattern of associations observed.

Interpretation of results

Our results are broadly consistent with previous studies examining outlet density and hospital admissions for alcohol-related conditions described in the literature review (Tatlow et al., 2000; Livingston, 2011; Stockwell et al., 2013; Fone et al., 2016; Richardson et al., 2015). However, a key novel aspect of our study was that we examined subcategories of on-trade and off-trade outlets, which had not been carried out previously.

With regard to on-trade outlets, we found associations between pubs, bars and nightclubs and both acute and chronic conditions wholly attributable to alcohol, as we had expected. The strongest link we observed was between pubs, bars and nightclubs and admissions for alcoholic liver disease. We also observed associations between both restaurants and other on-trade outlets and acute and chronic wholly attributable conditions, which we had not expected. The other on-trade outlets was a heterogenous group of outlets but restaurants are a clearly defined category and merit further investigation to establish if there is a causal link or if the association is explained by other factors.

With regard to off-trade outlets, we found that convenience stores were associated with both acute and chronic wholly attributable conditions, whilst supermarkets only had minimal associations with both, broadly in line with our prior expectations. Other off-trade outlets were a heterogenous group and whilst they were positively associated with chronic wholly attributable conditions, there was an apparent negative association with acute wholly attributable conditions. Possible explanations for the latter include negative confounding and a chance finding.

With regard to effect modification, we observed that for both acute and chronic wholly attributable conditions, the strength of associations for on-trade outlets increased with increasing age. This was the pattern we expected for chronic conditions which typically result from the cumulative effects of excessive alcohol consumption over a prolonged period of time. However, we expected stronger associations with acute conditions in younger people amongst whom binge drinking is more prevalent. It is interesting to note that associations with outlet density in men and women were broadly similar even though alcohol-related admission rates we observed in this study, and alcohol-related mortality rates which we had previously reported on (Erskine et al., 2010), were noticeably higher in men. Similarly, alcohol-related admission rates we observed here, and mortality rates we reported previously, were higher in more socioeconomically deprived areas, but there was no evidence that the outlets effect was stronger in more deprived areas.

Whilst Stockwell et al (2013) observed that alcohol price changes exerted effects observable at zero lag for acute alcohol-related conditions but which only became apparent from a two-year lag onwards for chronic conditions, we found no noticeable lagged effects for outlet density. Current and previous outlet densities were, however, quite highly correlated which would have reduced our chances of detecting lagged effects.

It has been postulated that increases in availability of alcohol may have diminishing effects as baseline availability increases (Livingston et al., 2007). Overall outlet density is generally relatively high in England. However, we did not observe any diminishing effects, and in fact observed that effects were much more noticeable in the highest density categories. With regard to the distance radii used to calculate density of outlets around postcode centroids, the 1-km radius was sufficient, and was the optimum radius amongst the distances we assessed, for detecting associations. Whilst more complex measures of density have been used in other studies, we felt that the method we used was intuitive and easy to interpret.

Limitations

Our study had a number of key strengths, including the novel use of detailed outlet types, the analysis of a substantial volume of hospital admissions data at a fine spatial scale with a temporal element, and examination of acute and chronic conditions wholly and partially attributable to alcohol. Nevertheless, there are a number of potential limitations to be considered.

We used an ecological study design which has recognised limitations, including ecological bias, which describes the situation where associations observed at the ecological (area) level are different from those which exist at the individual level. However, we used small geographical areas as the unit of analysis and exposures and population characteristics are likely to be more homogenous in smaller geographical areas, reducing the risk of ecological bias.

Hospital admissions data have a number of potential limitations. There are likely to be geographical variations in admission practices and in other factors influencing admission. We adjusted for this using several covariates but residual confounding cannot be ruled out. Spatial analysis adjusting for residual spatial autocorrelation on a subset of the data did not however substantially alter patterns of association observed. Inaccuracies in diagnosis and coding, variation in diagnostic and coding practices over time and by place and variation in depth of coding in the secondary diagnosis fields are further potential sources of error. There are also issues in relation to the methodology used for calculation of attributable fractions which could have over or underestimated the contribution of admissions partially attributable to alcohol.

Potential limitations of the alcohol outlets data also need to be considered. There may have been varying levels of completeness of data capture over time and by place. There may potentially have been issues in the accuracy of the data collected and maintained, including misclassification of outlet type, whether or not outlets were still in operation, duplicate records and inaccuracy in geolocation.

Other potential sources of error included inaccuracies in location of postcode centroids and reuse of postcodes over time. The level of socioeconomic deprivation in areas could have changed over time and in addition there could have been variation in deprivation levels within areas, although the use of small geographical areas would have minimised this to some extent. The urban-rural classification was relatively limited as the great majority of LSOAs were classified as

urban. There may have been inaccuracies in population denominator estimates causing error in expected admission counts. The project involved a substantial amount of complex data processing. Although we carried out extensive checks of all processes, including comparing counts extracted from HES data with counts obtained by Public Health England, GIS mapping to check outliers in the distribution of outlet density and checks to examine the use of "bucket" codes in HES data, the risk of processing error cannot be completely ruled out.

Although the effect of errors is generally to bias associations towards the null, in ecological analyses there is the risk of errors resulting in bias away from the null. In epidemiological studies, if associations are not causally linked, then potential explanations are bias, chance, confounding and reverse causality. We have considered bias and confounding, and chance findings remain a possibility although the substantial volume of data analysed reduced this likelihood. Reverse causality is another possible explanation as higher demand for alcohol could have led to an increase in outlet density. We had planned to explore the use of cross-lagged models to assess this possibility but the non-linear associations made this impractical. Therefore, although we have observed clear associations between alcohol outlet density and hospital admissions, our study cannot confirm if these associations are causally linked.

CONCLUSION

In conclusion, we found positive associations between outlet densities of all three categories of on-trade outlets (pubs, bars and nightclubs; restaurants; other on-trade outlets) and hospital admissions for both acute and chronic conditions wholly attributable to alcohol. With regard to off-trade outlets, the density of convenience stores was also positively associated with admissions for acute and chronic conditions attributable to alcohol. There was only modest evidence however of association between density of supermarkets in the local area and hospital admissions, and mixed evidence in relation to the other off-trade outlets category. The evidence from this national English study makes a substantial contribution to the evidence base on this topic in relation to licensing policy decisions.

Ethics approval

The study was approved by the University of Sheffield (School of Health and Related Research) Research Ethics Committee.

Availability of data and material

The data on alcohol outlets may be obtained from CGA Strategy. (http://www.cgastrategy.co.uk/). Data on hospital admissions in England may be obtained from the Health and Social Care Information Centre (http://www.hscic.gov.uk/).

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TECHNICAL APPENDIX

Lagged effects of outlet density on admissions

We investigated lagged effects of outlet density on acute and chronic admissions wholly attributable to alcohol. Our prior hypothesis was that acute admissions would be more strongly associated with concurrent outlet density (i.e. in the same year) while chronic admissions would be more strongly associated with outlet density in previous years.

We used one on-trade outlets category – pubs, bars and nightclubs – and one off-trade outlets category – convenience stores – to investigate lagged effects. Both were categories with positive associations with both acute and chronic conditions wholly attributable to alcohol.

We compared associations using outlet density in the concurrent year with outlet densities one and two years ago, and the results are shown in Table 12.

Effect sizes were very similar for all three measures of exposure to outlet density. In particular, there was no evidence to suggest that concurrent outlet density was more strongly associated with acute conditions and outlet density in previous years more strongly associated with chronic conditions.

The above analysis was limited by the fact that outlet density was interpolated for years where there were no data on outlets from CGA and Nielsen.

A further analysis was therefore carried out limiting the admissions data examined to years where there were concurrent, as well as a previous set of, outlets data from CGA and Nielsen. To recap, datasets on outlets were available for 2003, 2007, 2010 and 2013. Concurrent exposure effects were assessed using exposure and outcome data in the same year (2007, 2010 and 2013). Effect of previous exposure was assessed using: 2003 outlets with 2007 outcomes; 2007 outlets with 2010 outcomes; and 2010 outlets with 2013 outcomes.

The results are shown in Table 13. Effect sizes were very similar for concurrent and previous exposure measures. The effect sizes for concurrent years vary slightly from the main analysis results because they are based on a subset of the data (i.e. 3 instead of 12 years).

Table 12. LAGGED effect of outlet density measures (one and two year lags) on acute and chronic conditions wholly attributable to alcohol; pubs, bars and nightclubs and convenience stores, England 2002/03 to 2013/14. Rate ratios (95% CI) for category by quartile of outlet density for men and women combined are shown (outlet density within a 1-km radius of a postcode centroid, averaged for all postcodes within an LSOA).

Alcohol outlet category, outcome and exposure lag	**Rate ratios for alcohol outlet categories by quartile (1=lowest; 4=highest)**			
	1	2	3	4
Pubs, bars, nightclubs				
Acute conditions				
Exposure lag				
- Concurrent year	1	1.03 (1.02 - 1.04)	1.05 (1.04 - 1.06)	1.13 (1.11 - 1.15)
- One year ago	1	1.03 (1.02 - 1.05)	1.05 (1.04 - 1.07)	1.13 (1.11 - 1.15)
- Two years ago	1	1.03 (1.02 - 1.05)	1.05 (1.04 - 1.07)	1.13 (1.11 - 1.15)
Chronic conditions				
Exposure lag				
- Concurrent year	1	1.04 (1.02 - 1.05)	1.06 (1.05 - 1.08)	1.22 (1.21 - 1.24)
- One year ago	1	1.03 (1.02 - 1.05)	1.07 (1.05 - 1.08)	1.23 (1.21 - 1.25)
- Two years ago	1	1.04 (1.02 - 1.05)	1.07 (1.06 - 1.09)	1.23 (1.21 - 1.25)
Convenience stores				
Acute conditions				
Exposure lag				
- Concurrent year	1	1.04 (1.03 - 1.05)	1.06 (1.05 - 1.07)	1.10 (1.09 - 1.12)
- One year ago	1	1.04 (1.03 - 1.05)	1.06 (1.05 - 1.08)	1.10 (1.09 - 1.12)
- Two years ago	1	1.04 (1.03 - 1.05)	1.07 (1.06 - 1.08)	1.10 (1.08 - 1.11)
Chronic conditions				
Exposure lag				
- Concurrent year	1	1.02 (1.01 - 1.03)	1.03 (1.02 - 1.04)	1.07 (1.06 - 1.09)
- One year ago	1	1.03 (1.02 - 1.04)	1.03 (1.02 - 1.04)	1.08 (1.06 - 1.09)
- Two years ago	1	1.03 (1.01 - 1.04)	1.03 (1.02 - 1.04)	1.08 (1.06 - 1.09)

Table 13. LAGGED effect (3-4 year lag)* of outlet density measures limiting the outcome data examined to years where there was a concurrent as well as a previous set of outlets data provided by CGA (i.e. 2007, 2010 and 2013). Acute and chronic conditions wholly attributable to alcohol were examined in relation to pubs, bars and nightclubs and convenience stores, England. Rate ratios (95% CI) for category by quartile of outlet density for men and women combined are shown (outlet density within a 1-km radius of a postcode centroid, averaged for all postcodes within an LSOA).

Alcohol outlet category, outcome and exposure lag*	**Rate ratios for alcohol outlet categories by quartile (1=lowest; 4=highest)**			
	1	2	3	4
Pubs, bars, nightclubs				
Acute conditions				
Exposure lag				
- Concurrent year	1	1.03 (1.01 - 1.06)	1.05 (1.03 - 1.08)	1.13 (1.10 - 1.16)
- Previous exposure	1	1.04 (1.02 - 1.06)	1.06 (1.03 - 1.08)	1.14 (1.10 - 1.17)
Chronic conditions				
Exposure lag				
- Concurrent year	1	1.03 (1.01 - 1.06)	1.07 (1.05 - 1.10)	1.25 (1.22 - 1.29)
- Previous exposure	1	1.03 (1.00 - 1.05)	1.08 (1.05 - 1.11)	1.24 (1.20 - 1.27)
Convenience stores				
Acute conditions				
Exposure lag				
- Concurrent year	1	1.05 (1.03 - 1.07)	1.08 (1.05 - 1.10)	1.10 (1.07 - 1.12)
- Previous exposure	1	1.04 (1.02 - 1.06)	1.06 (1.04 - 1.08)	1.10 (1.08 - 1.12)
Chronic conditions				
Exposure lag				
- Concurrent year	1	1.03 (1.00 - 1.05)	1.03 (1.00 - 1.05)	1.06 (1.03 - 1.08)
- Previous exposure	1	1.02 (1.00 - 1.04)	1.03 (1.01 - 1.05)	1.07 (1.05 - 1.10)

* Datasets on outlets were provided by CGA for 2003, 2007, 2010 and 2013. Concurrent exposure effects were assessed using exposure and outcome data in the same year (2007, 2010 and 2013). Effect of previous exposure was assessed using: 2003 outlets with 2007 outcomes; 2007 outlets with 2010 outcomes; and 2010 outlets with 2013 outcomes.

Effect of varying distance radii for calculating outlet density

All the previous analyses were based on outlet density measures calculated using a 1-km radius around residential postcode centroids. In order to examine the effects of using different distance radii, we also calculated densities using 250m, 3-km and 5-km radii around postcode centroids, and examined associations with admissions due to acute conditions wholly attributable to alcohol. The associations were examined using two outlet categories: pubs, bars and nightclubs; and convenience stores.

The results are shown in Table 14. For pubs, bars and nightclubs, using a 250m radius generated patterns which were broadly similar to results obtained using the 1-km radius. With larger radii, however, the effect size diminished in the highest density category.

For convenience stores, use of the 250m radius gave results which were broadly similar to those obtained using the 1-km radius. Use of the larger radii, however, abolished the positive association, and paradoxically produced apparently negative associations.

Increasing radii would be expected to dilute any associations towards the null but not generate negative associations. We investigated this further by repeating the analyses with the outlet density included as the only explanatory variable, and the results are also presented in Table 14. There was no longer any evidence of the negative associations. This indicates that the apparent negative associations were related to inclusion of other explanatory factors.

The unadjusted effect sizes were larger indicating that the effects were confounded by the other variables, including other outlet types, which is not unexpected as several of the variables were positively correlated.

Table 14. Effect of varying the **DISTANCE RADII** used to calculate outlet density on the associations between alcohol outlet density and acute admissions wholly attributable to alcohol; examined in relation to pubs, bars and nightclubs and convenience stores, England 2002/03 to 2013/14. Rate ratios (95% CI) for category by quartile of outlet density for men and women combined are shown (outlet density within the specified radius of a postcode centroid, averaged for all postcodes within an LSOA).

Alcohol outlet category and distance band	**Rate ratios for alcohol outlet categories by quartile (1=lowest; 4=highest)**			
	1	2	3	4
Models incorporating all covariates				
Pubs, bars, nightclubs				
Distance band				
- 250m radius	1	1.01 (1.00 - 1.02)	1.02 (1.01 - 1.03)	1.13 (1.12 - 1.14)
- 1km radius	1	1.03 (1.02 - 1.04)	1.05 (1.04 - 1.06)	1.13 (1.11 - 1.15)
- 3km radius	1	1.05 (1.03 - 1.06)	1.06 (1.04 - 1.08)	1.08 (1.05 - 1.10)
- 5km radius	1	1.01 (1.00 - 1.03)	1.03 (1.01 - 1.05)	1.04 (1.02 - 1.07)
Convenience stores				
Distance band				
- 250m radius	1	1.03 (1.02 - 1.04)	1.04 (1.04 - 1.05)	1.07 (1.06 - 1.08)
- 1km radius	1	1.04 (1.03 - 1.05)	1.06 (1.05 - 1.07)	1.10 (1.09 - 1.12)
- 3km radius	1	0.94 (0.93 - 0.96)	0.95 (0.93 - 0.96)	0.92 (0.91 - 0.94)
- 5km radius	1	0.95 (0.94 - 0.97)	0.95 (0.93 - 0.96)	0.91 (0.89 - 0.93)
Models with outlet type as the only covariate				
Pubs, bars, nightclubs				
Distance band				
- 250m radius	1	0.99 (0.98 - 1.00)	1.13 (1.12 - 1.14)	1.42 (1.41 - 1.44)
- 1km radius	1	1.32 (1.31 - 1.33)	1.46 (1.44 - 1.47)	1.73 (1.71 - 1.75)
- 3km radius	1	1.47 (1.45 - 1.48)	1.57 (1.56 - 1.59)	1.66 (1.64 - 1.68)
- 5km radius	1	1.33 (1.32 - 1.34)	1.47 (1.45 - 1.49)	1.40 (1.39 - 1.42)
Convenience stores				
Distance band				
- 250m radius	1	1.12 (1.10 - 1.13)	1.21 (1.20 - 1.22)	1.41 (1.40 - 1.43)
- 1km radius	1	1.33 (1.32 - 1.35)	1.58 (1.57 - 1.60)	1.73 (1.72 - 1.75)
- 3km radius	1	1.42 (1.41 - 1.44)	1.73 (1.71 - 1.74)	1.61 (1.59 - 1.62)
- 5km radius	1	1.36 (1.35 - 1.38)	1.60 (1.58 - 1.61)	1.44 (1.42 - 1.45)

Effect of adjusting for unstructured and spatially structured random effects

The standard models used so far in this report incorporated a range of covariates including year, sex, area-level socioeconomic deprivation and urban-rural status, non-alcohol related admissions as a proxy for general health service factors influencing admission and lung cancer admissions as a proxy for "unhealthy" areas, with expected counts standardised for age.

However, other factors unaccounted for in our analyses could have resulted in residual spatial autocorrelation influencing the associations we observed. We used Bayesian hierarchical modelling to investigate this aspect with models incorporating unstructured and spatially structured random effects. We examined the effects using admissions due to acute conditions wholly attributable to alcohol.

We were unable to run the spatial model for all 12 years combined due to the size of the dataset. We therefore ran the spatial model for individual years and the results are presented in Table 15. Because of the large number of rate ratios produced, for clarity we have only shown rate ratios for the highest outlet quartile category for each of the six outlet types. The table also shows the equivalent rate ratios by year obtained using the standard (non-spatial) models used throughout this report for comparison.

Although there was some variation between the results obtained with the spatial and non-spatial models, on the whole, the rate ratios were broadly comparable. More striking, however, was the substantial statistical variability in the rate ratios from year to year seen using both models. For example, for pubs, bars and nightclubs, the rate ratio from the standard model ranged from 1.04 (0.99 - 1.09) in 2007 to 1.20 (1.15 - 1.26) in 2012.

In addition, the table also presents results for models incorporating only unstructured random effects, which ran for data on all 12 years combined, and the equivalents from standard models. To aid comparison, we have also calculated a simple mean rate ratio of the results from models run for individual years. Although there were some differences, the rate ratios for each of the outlet types were generally broadly similar.

The results suggest that any residual spatial autocorrelation did not substantially alter the general pattern of associations observed using the standard non-spatial modelling approach.

Table 15. Effect of Bayesian hierarchical modelling incorporating unstructured and **SPATIALLY STRUCTURED** random effects on rate ratios compared with the standard modelling approach. Rate ratios (95% CI) are for acute conditions wholly attributable to alcohol and are shown only for the highest outlet density category by quartile for men and women combined (outlet density within a 1-km radius of a postcode centroid, averaged for all postcodes within an LSOA); England 2002/03 to 2013/14.

Outlet type and Year	**Standard analysis**	**Bayesian analysis**	**Outlet type and Year**	**Standard analysis**	**Bayesian analysis**
Pubs, bars, nightclubs			***Supermarkets***		
	Standard analysis	Incorporating unstructured and spatially structured random effects		Standard analysis	Incorporating unstructured and spatially structured random effects
2002	1.04 (0.98 - 1.11)	1.04 (0.96 - 1.14)	2002	1.06 (1.01 - 1.11)	1.02 (0.96 - 1.08)
2003	1.13 (1.06 - 1.20)	1.13 (1.04 - 1.23)	2003	1.05 (1.01 - 1.09)	1.04 (0.98 - 1.10)
2004	1.08 (1.02 - 1.14)	1.10 (1.02 - 1.19)	2004	0.99 (0.95 - 1.03)	1.00 (0.95 - 1.05)
2005	1.10 (1.04 - 1.15)	1.10 (1.03 - 1.19)	2005	1.04 (1.00 - 1.08)	1.07 (1.02 - 1.12)
2006	1.14 (1.08 - 1.19)	1.17 (1.09 - 1.26)	2006	1.00 (0.96 - 1.03)	1.02 (0.97 - 1.07)
2007	1.04 (0.99 - 1.09)	1.09 (1.02 - 1.17)	2007	1.04 (1.01 - 1.08)	1.07 (1.02 - 1.12)
2008	1.08 (1.03 - 1.13)	1.10 (1.03 - 1.18)	2008	1.03 (0.99 - 1.06)	1.02 (0.98 - 1.07)
2009	1.11 (1.07 - 1.16)	1.10 (1.03 - 1.17)	2009	1.03 (1.00 - 1.07)	1.05 (1.00 - 1.09)
2010	1.14 (1.09 - 1.18)	1.14 (1.07 - 1.21)	2010	1.02 (0.99 - 1.05)	1.02 (0.97 - 1.06)
2011	1.18 (1.13 - 1.23)	1.12 (1.05 - 1.20)	2011	1.00 (0.97 - 1.03)	0.99 (0.95 - 1.04)
2012	1.20 (1.15 - 1.26)	1.18 (1.10 - 1.26)	2012	1.03 (1.00 - 1.06)	1.02 (0.98 - 1.07)
2013	1.18 (1.13 - 1.23)	1.12 (1.05 - 1.20)	2013	1.08 (1.05 - 1.11)	1.08 (1.03 - 1.13)
Mean rate ratio	1.12	1.12	Mean rate ratio	1.03	1.03
	Standard analysis	Incorporating unstructured random effects only		Standard analysis	Incorporating unstructured random effects only
2002/03 – 2013/14	1.13 (1.11 - 1.15)	1.09 (1.08 - 1.11)	2002/03 – 2013/14	1.03 (1.02 - 1.04)	1.05 (1.04 - 1.06)

Table 15 (continued)

Outlet type and Year	Standard analysis	Bayesian analysis	Outlet type and Year	Standard analysis	Bayesian analysis
Restaurants			***Convenience stores***		
	Standard analysis	Incorporating unstructured and spatially structured random effects		Standard analysis	Incorporating unstructured and spatially structured random effects
2002	1.08 (1.02 - 1.14)	1.17 (1.08 - 1.26)	2002	1.18 (1.13 - 1.24)	1.03 (0.96 - 1.10)
2003	1.03 (0.97 - 1.08)	1.08 (1.00 - 1.16)	2003	1.22 (1.17 - 1.27)	1.06 (0.99 - 1.12)
2004	1.10 (1.05 - 1.16)	1.11 (1.04 - 1.19)	2004	1.16 (1.11 - 1.20)	1.04 (0.98 - 1.10)
2005	1.02 (0.98 - 1.07)	1.05 (0.98 - 1.12)	2005	1.12 (1.08 - 1.16)	1.05 (1.00 - 1.11)
2006	1.02 (0.98 - 1.06)	0.99 (0.93 - 1.05)	2006	1.10 (1.06 - 1.14)	1.04 (0.99 - 1.10)
2007	1.14 (1.09 - 1.19)	1.07 (1.01 - 1.13)	2007	1.16 (1.12 - 1.20)	1.08 (1.03 - 1.14)
2008	1.11 (1.07 - 1.16)	1.05 (0.99 - 1.12)	2008	1.11 (1.07 - 1.15)	1.08 (1.03 - 1.13)
2009	1.18 (1.14 - 1.23)	1.12 (1.06 - 1.18)	2009	1.09 (1.05 - 1.12)	1.08 (1.03 - 1.14)
2010	1.14 (1.10 - 1.19)	1.11 (1.05 - 1.17)	2010	1.12 (1.08 - 1.15)	1.06 (1.01 - 1.11)
2011	1.08 (1.04 - 1.13)	1.08 (1.02 - 1.14)	2011	1.12 (1.08 - 1.16)	1.10 (1.04 - 1.16)
2012	1.03 (0.99 - 1.07)	1.03 (0.97 - 1.09)	2012	1.06 (1.02 - 1.10)	1.07 (1.02 - 1.13)
2013	1.11 (1.06 - 1.15)	1.11 (1.04 - 1.17)	2013	1.03 (0.99 - 1.07)	1.03 (0.98 - 1.09)
Mean rate ratio	1.09	1.08	Mean rate ratio	1.12	1.06
	Standard analysis	Incorporating unstructured random effects only		Standard analysis	Incorporating unstructured random effects only
2002/03 – 2013/14	1.09 (1.07 - 1.10)	1.03 (1.02 - 1.04)	2002/03 – 2013/14	1.10 (1.09 - 1.12)	1.09 (1.08 - 1.10)

Table 15 (continued)

Outlet type and Year	Standard analysis	Bayesian analysis	Outlet type and Year	Standard analysis	Bayesian analysis
Other on-trade outlets			***Other off-trade outlets***		
	Standard analysis	Incorporating unstructured and spatially structured random effects		Standard analysis	Incorporating unstructured and spatially structured random effects
2002	1.18 (1.11 - 1.26)	1.02 (0.94 - 1.11)	2002	0.84 (0.80 - 0.88)	0.97 (0.89 - 1.05)
2003	1.18 (1.11 - 1.25)	1.07 (0.99 - 1.16)	2003	0.88 (0.84 - 0.92)	0.98 (0.91 - 1.06)
2004	1.12 (1.06 - 1.18)	1.03 (0.96 - 1.11)	2004	0.88 (0.84 - 0.93)	0.95 (0.88 - 1.02)
2005	1.18 (1.12 - 1.23)	1.08 (1.01 - 1.16)	2005	0.88 (0.84 - 0.92)	0.96 (0.90 - 1.02)
2006	1.15 (1.10 - 1.21)	1.10 (1.03 - 1.17)	2006	0.86 (0.83 - 0.90)	0.95 (0.89 - 1.02)
2007	1.12 (1.07 - 1.17)	1.08 (1.02 - 1.15)	2007	0.89 (0.86 - 0.93)	0.97 (0.91 - 1.04)
2008	1.14 (1.09 - 1.20)	1.13 (1.06 - 1.20)	2008	0.91 (0.87 - 0.94)	0.99 (0.93 - 1.06)
2009	1.03 (0.99 - 1.08)	1.01 (0.96 - 1.08)	2009	0.89 (0.86 - 0.93)	1.01 (0.95 - 1.08)
2010	1.10 (1.06 - 1.15)	1.10 (1.04 - 1.16)	2010	0.88 (0.85 - 0.92)	0.99 (0.93 - 1.05)
2011	1.08 (1.03 - 1.12)	1.08 (1.01 - 1.14)	2011	0.89 (0.86 - 0.93)	0.98 (0.92 - 1.04)
2012	1.18 (1.13 - 1.23)	1.13 (1.06 - 1.20)	2012	0.90 (0.87 - 0.94)	1.01 (0.95 - 1.08)
2013	1.10 (1.06 - 1.15)	1.08 (1.02 - 1.15)	2013	0.91 (0.87 - 0.94)	0.97 (0.91 - 1.03)
Mean rate ratio	1.13	1.08	Mean rate ratio	0.88	0.98
	Standard analysis	Incorporating unstructured random effects only		Standard analysis	Incorporating unstructured random effects only
2002/03 – 2013/14	1.12 (1.10 - 1.14)	1.10 (1.09 - 1.12)	2002/03 – 2013/14	0.88 (0.87 - 0.89)	0.94 (0.93 - 0.95)