Simulating the density reduction and equity-impact of potential tobacco retail control policies.

Fiona M Caryl[1], Jamie Pearce[2], Garth Reid[3], Rich Mitchell[1], Niamh K Shortt[2]

1 MRC/CSO Social & Public Health Sciences, Institute of Health & Wellbeing, University of Glasgow, Glasgow, UK

2 Centre for Research on Environment, Society and Health, School of GeoSciences, University of Edinburgh, Edinburgh, UK

3 Department of Public Health Sciences, NHS Health Scotland, Edinburgh, UK

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Abstract

Background: Reducing the provision of tobacco is important for decreasing inequalities in smoking and smoking-related harm. Various policies have been proposed to achieve this, but their impacts—particularly on equity—are often unknown. Here, using national-level data, we simulate the impacts of potential policies designed to reduce tobacco outlet density (TOD).

Methods: Tobacco retailer locations (n=9030) were geocoded from Scotland's national register, forming a baseline. Twelve policies were developed in three types: 1. Regulating type of retailer selling tobacco; 2. Regulating location of tobacco sales; 3. Area-based TOD caps. Density reduction was measured as mean percentage reduction in TOD across data zones and number of retailers nationally. Equity-impact was measured using regression-based Relative Index of Inequality (RII) across income deprivation quintiles.

Results: Policies restricting tobacco sales to a single outlet type ("Supermarket"; "Liquor store"; "Pharmacy") caused >80% TOD reduction and >90% reduction in the number of tobacco outlets nationally. However, RIIs indicated that two of these policies ("Liquor store", "Pharmacy") increased socioeconomic inequalities in TOD. Equity-promoting policies included "Minimum spacing" and exclusion zones around "Child spaces". The only policy to remove statistically significant TOD inequalities was the one deliberately targeted to do so ("Reduce clusters").

Conclusions: Using spatial simulations, we show that all selected policies reduced provision of tobacco retailing to varying degrees. However, the most 'successful' at doing so also increased inequalities. Consequently, policymakers should consider how the methods by which tobacco retail density is reduced, and success measured, align with policy aims.

Introduction

A large body of evidence suggests a link between tobacco availability and tobacco use [1–7], including robust longitudinal evidence [8]. Whilst reducing the local availability of tobacco is viewed as the next critical step in tobacco control [9], interventions in this area have been underutilised. Indeed, availability interventions, which may be spatial (e.g. exclusion zones around schools) or temporal (e.g. restricting hours of sales), have not been utilised to the same degree as those pertaining to price and marketing.

The pathways between greater availability to tobacco retailers and smoking behaviours are multiple. Research suggests that greater tobacco outlet density (TOD) increases opportunities to purchase tobacco; creates competitive local markets that may drive product costs down; and normalises tobacco products [6,10,11]. TOD is also strongly patterned by socioeconomic status, with disproportionately higher availability in more deprived areas [12–14]. Recent research shows that despite a variety of tobacco control policy interventions, socioeconomic inequalities in the availability of tobacco are growing [15].

Potential policy solutions to reduce TOD across neighbourhoods include restricting the types of businesses that can sell tobacco, such as only liquor stores, and regulating where tobacco retailers can locate, such as exclusion zones around schools [16]. Some studies have quantified the impact of such policies on overall TOD [17,18], or the cost of tobacco products [19,20]. Few studies have explicitly focused on the equity-impact of prospective policy interventions to control tobacco availability, but those that have showed that the equity-impacts of different policy options vary widely [21–23]. For example, the removal of tobacco sales from US pharmacies had no impact on existing racial/ethnic and socioeconomic disparities in TOD across neighbourhoods [21]; whereas banning tobacco sales within 1000 feet of schools may either reduce or eliminate existing disparities [22]. Exploring four policy options, Marsh et al. (2020) found that whilst there would be an overall reduction in tobacco availability, its socioeconomic gradient would persist under each option [23]. In modelling the impact of theoretical tobacco control policy options on tobacco cost across two levels of population density and two levels of income, Luke et al. (2017) showed that there is no "one size fits all" retailer reduction policy. Rather, policy impacts are context dependent and vary depending on retailer density starting points [24].

It is widely accepted that public health interventions do not always benefit everyone equally, and that some may increase health inequalities [25,26]. It is therefore important that the impacts of policies aimed at reducing the provision of tobacco retailing for the entire population and/or reducing health inequalities be explicitly evaluated. Simulations offer one way to understand the potential impacts of competing policy options, particularly how they differentially effect the whole population or high-risk groups [27]. Here we use national-level data from Scotland to simulate tobacco retail environments under potential policies aimed at reducing TOD. We evaluate how well they reach two aims, relative to the base-line situation: 1. Maximise overall reductions in TOD; 2. Minimise avoidable and unfair socioeconomic inequalities in TOD [28].

Methods

Policy scenarios

Potential policies were developed based on a rapid evidence review carried about by NHS Health Scotland [7] on previously considered policies [17,19,22,24,29], and literature on smokers' behaviour (see scenarios below). Policies formed one of three types: 1. regulating types of retailer able to sell tobacco; 2. regulating sales within specific settings, and 3. capping the number of retailers (regardless of the type or setting of retailers) within local areas. When developing policies, we deliberately included one option that was specifically targeted at reducing socioeconomic inequalities (policy 12, below). The face validity of proposed policies was assessed with professionals working in the public health and tobacco advocacy fields to produce the following:

1. Frequent purchases - Prohibit tobacco sales in outlet types most frequently accessed by smokers, thereby removing important environmental cues. This included supermarkets, newsagents, convenience stores, and service stations [4,30,31].
2. On-Sales - Prohibit tobacco sales in premises licensed for on-site alcohol consumption, where tobacco use is increased, and relapses from cessation attempts more likely [4,32]. This included pubs, restaurants, and private clubs.
3. Liquor store - Restrict tobacco sales to off-site licensed alcohol stores only , creating higher travel costs (fuel/time) associated with tobacco purchases [19,20].
4. Pharmacy - Restrict tobacco sales to pharmacies only, creating higher travel costs (fuel/time) associated with tobacco purchases. Tobacco is not currently sold by UK pharmacies, but pharmacists are well placed to provide advice on smoking cessation services [33].
5. Supermarket - Restrict tobacco sales to supermarkets only; supermarkets are perceived to have strict requirements for age identification so tend to be avoided by underage smokers attempting direct purchases [34].
6. Small local - Prohibit tobacco sales in small, local shops; such shops are commonly targeted by underage smokers who perceive that shop owners overlook age identification or proxy purchases [34]. This included newsagents, convenience stores,

and shops registered as type 'other retail' (e.g. discount shops) in the national tobacco register.

7. Schools - Prohibit tobacco sales within 300m of schools, as higher densities of retailers near schools have been associated with higher tobacco use amongst youths [11]. An exclusion distance of 300m was chosen as the midpoint of the 150, 300 and 450m distances modelled by Luke et al. (2017) [24].
8. Child spaces - Prohibit tobacco sales within 300m of child spaces, which included playgrounds and playing fields in addition to schools. An exclusion distance of 300m was chosen as the midpoint of the 150, 300 and 450m distances modelled by Luke et al. (2017).
9. Cap Nat Av - Cap the number of retailers per 1,000 population for each data zone at the national average for all data zones.
10. Cap Least Deprived - Cap the number of retailers per 1,000 population for each data zone at the average of the least income deprived quintile of data zones ("Cap Least Deprived").
11. Min Spacing - Require minimum spacing (300m) between tobacco retailers to prevent clustering of outlets in deprived areas [13]. A minimum distance of 300m was chosen as the midpoint of the 150, 300 and 450m distances modelled by Luke et al. (2017).
12. Reduce clusters - Prohibit tobacco sales in outlet types that are overrepresented in the most deprived areas. Evidence suggest that certain types of retail outlet are more common in deprived areas [13,35]. To produce a policy specifically targeted at reducing inequalities we determined which retailer types showed the greatest disparities among deprivation quintiles. . We found that discount shops, liquor stores, take-aways, cafes, newsagents, convenience stores, nightclubs, and pubs were 5 times

more abundant in the two most deprived quintiles of areas than the least deprived areas, so we prohibited tobacco sales from these.

Measuring tobacco outlet density

Addresses of tobacco retail outlets in 2016 were obtained from the Register of Tobacco and Nicotine Vapour Product Retailers (n=9030: online supplemental table 1) and geocoded using the R package ggmap [36]. We created a baseline measure of outlet density for every data zone in Scotland (n = 6,976) to compare with the outlet geographies that policy interventions would create. Data zones are census reporting units in Scotland comprising 500-1000 residents. Tobacco outlet locations were mapped and Kernel Density Estimation (KDE) was used to produce a continuous surface density of outlets that was unconstrained by area-unit boundaries. The KDE process divides Scotland into 100x100 m grid cells and assesses the number and proximity of outlets within an 800 m radius of each cell (chosen as a plausible walking distance). The process repeats as a ‘moving window’, measuring the 800m context of each cell. Outlets nearer the centre of the search window are given greater weight than those further away. Hence the KDE value represents a proximity-weighted estimate of the density of each outlet per km^2. This was converted to TOD per 1,000 population per km^2 using census data for the data zone in which the KDE cell was located. This method has advantages over other density measures as it considers density and proximity together [5], which is important given the spatial clustering of tobacco retail outlets in deprived areas [13]. We assigned each data zone the KDE value for the cell in which its population-weighted centroid was located to reflect the density of outlets where most of the population reside. This process was repeated for each of the simulated environments resulting from the 12 policy scenarios.

Income deprivation

We obtained an indicator of income deprivation for each data zone from the Scottish Government's Scottish Index of Multiple Deprivation (SIMD 2016: https://www2.gov.scot/Topics/Statistics/SIMD). This indicates the proportion of population in the area receiving means-tested benefits and government support, eligibility for which is based on income and savings.

Simulating retail environments under policy scenarios

When describing our simulations, we stress that any reference to 'reductions in TOD' refers only to businesses ceasing to trade in tobacco products only, and not ceasing trade altogether. All entries to the Register of Tobacco and Nicotine Vapour Product Retailers include information about the outlet type, so policy scenarios involving prohibiting tobacco sales by type (Policies 1—3 and 5—6) were simply subsets of the baseline retail dataset. Pharmacies in the UK do not sell tobacco products, so are not on the register. To simulate restriction of sales to pharmacies (Policy 4), all current outlet tobacco retailers locations were removed and replaced by pharmacy locations (n=1,213). geocoded from NHS Digital (https://digital.nhs.uk: accessed 30/09/2018). To simulate Policies 7 (Schools) and 8 (Child spaces), we obtained polygon boundaries of all schools, playgrounds and playing fields in Scotland from OS Mastermap (OS MasterMap Topography Layer, Ordnance Survey, GB. Accessed January 2019). The straight-line distance from each polygon to each retailer was measured and tobacco retail locations falling <300m of a school (Policy 7), or child space (Policy 8), were removed. A straight-line distance was chosen as it is more conservative than a street-network distance [37]. To cap densities of tobacco retailers in data zones (Policies 9—10), we first calculated the mean number of tobacco retailers per 1,000 population across all data zones (1.72 retailers per 1,000 population), and then the mean number of tobacco retailers per 1,000 population in the least income deprived quintile of data zones (0.82 retailers per 1,000 population). These mean values were used to determine the number of tobacco retail locations to be randomly removed in each data zone to meet each cap. As this process was stochastic, we took a conservative approach. The random removal was repeated 10 times for each target cap and the set with the most retailers remaining was retained (in keeping with the default of package used for removing retailers within distance). To achieve a minimum spacing between retailers (Policy 11) we used a function in the spThin package [38] to thin spatial points at random to a user-specified minimum straight-line distance requirement (300m). Again, this stochastic process was repeated 10 times and the subset with the maximum number of points retained. Finally, to create a policy targeted to reduce inequalities, we identified which outlet types were more than 5 times more common in the two most deprived quintiles than the least deprived quintile (Policy 12: online supplemental table 1), which were removed from the baseline set.

Quantifying TOD reduction and equity-impact

We assessed our policy scenarios on two outcomes: density reduction and equity-impact, each of which was quantified in two ways. Density reduction was measured as: 1. Mean percentage reduction in per capita TOD per data zone against the baseline per capita TOD for that data zone (henceforth TOD refers to per capita TOD); and 2. the percentage reduction in number of retailers nationally. We measured equity-impact by: 1. Fitting regressions to mean TOD across income deprivation quintiles to test for statistical differences, and 2. Using the Relative Index of Inequality (RII) [39]. The regression line fitted to the mean TOD of each income quintile has the form y=α+βx. The regression slope β is designated the Slope Index of Inequality (SII), which is interpreted as the average difference in TOD with each quintile of deprivation ranked from lowest to highest. As we are comparing TOD, a negative SII represents a *decrease* in TOD as socioeconomic position improves. The RII is the ratio of the value at the most deprived end of the fitted regression line (corresponding to the intercept: α) to the value at the least deprived end of the fitted regression line (corresponding to the intercept + slope * x). An RII equal to one indicate parity across socioeconomic levels. RII greater than one indicates the relative magnitude of the inequality. All analysis was conducted in R Programming Environment [40].

Results

Density reduction

At baseline there were 9030 tobacco retailers across Scotland, with a mean per capita TOD across all data zones of 7.6 (95% CI: 7.4—7.9) retailers per 1,000 population. The most effective policies at reducing both the number of retailers nationally and mean TOD were those restricting tobacco sales to a single outlet type (“Supermarket”; “Liquor store”; “Pharmacy”: table 1). “Supermarket” reduced mean TOD by 86.4% (95% CI: 85.7—87.1%) and reduced national retailer number to 489 (94.6% fewer than baseline). “Liquor store” reduced mean density by 85.9% (95% CI: 85.2—86.5%) and national retailer number to 537 (94.1% fewer). “Pharmacy” reduced mean TOD by 75.0% (95% CI: 73.4—76.5%) and national retailer number to 1213 (86.6% fewer). Three other policies reduced mean TOD and number of retailers nationally by more than 60%. “Reduce clusters” reduced mean TOD by 74.9% (95% CI: 74.1—75.7%) and national retailer number to 1932 (78.6% fewer). “Child spaces” reduced mean TOD by 72.9% (95% CI: 72.1—73.8%) and national retailer number to 2646 (70.7% fewer). “Frequent purchases” reduced mean TOD by 69.6% (95% CI: 68.9—70.3%) and national retailer number to 2769 (69.3% fewer). The least effective policy was “On-sales”, which reduced mean TOD by 15.4% (95% CI: 14.6—16.2%) and the number of retailers nationally to 6873 (23.9% fewer). Estimates of mean per capita TOD in each area-level deprivation quintile for each policy are given in online supplemental table 2.

Equity-impact

The RII at baseline indicated a significant 2.6-fold difference in mean TOD between the most and least deprived quintiles (table 2). Only one policy—" Reduce clusters", a policy specifically designed to target deprived areas—reduced inequalities such that there was no longer a statistically significant difference (p= 0.067) in mean TOD between least and most deprived quintiles. However, inspection of RIIs indicated that several other policies greatly reduced inequalities from baseline, if not to statistical significance. Other than "Reduce clusters", particularly equity-promoting policies (e.g. those ranked below baseline in table 2) included "Supermarket", "Small local", "Frequent purchases", and "Child spaces". Some policies, such as "On-sales", "Liquor store" and "Pharmacy", were found to increase socioeconomic inequalities in mean TOD (e.g. those are ranked above baseline in table 2).

Discussion

We evaluated changes to tobacco retail environments under a range of potential scenarios. We found that policies varied in their effectiveness at reducing mean TOD, from a minimum of 15% (banning tobacco sales from premises licensed for on-site alcohol consumption) to a maximum of 86% (tobacco sold at supermarkets only), resulting in 23.9% to 94.6% fewer retailers selling tobacco products nationally. Eight of the 12 simulated policies reduced mean per capita density by over 50%, but the most restrictive policies—those limiting sales to a single outlet type—were the most effective at reducing mean TOD. Relative Indices of Inequality (RII) showed that several policies were more equitable than our business-as-usual baseline, including removing outlets that are more prolific in the most deprived areas, allowing sales at supermarkets only, removing sales from small local stores, removing sales from stores where tobacco is most frequently purchased, and removing sales from stores within 300m of child spaces. However, three policies (banning tobacco sales in premises with on-site alcohol consumption, and allowing sales in liquor stores only, or pharmacies only)—the latter two of which caused the greatest reductions in TOD—increased inequalities between the most and least deprived areas above the disparity seen at baseline.

Rather than identifying a single 'best' policy approach to tackle tobacco availability, our intention was to use simulations to provide comprehensive insight into how tobacco retail environments could change under different policy options. There are many ways to measure effectiveness or equity of policy impact, and policymakers may have different priorities on what targets policies should meet. One of the benefits of using simulations is that they allow policymakers to assess and compare impacts of interventions directly to inform debate and future policy ideas. We provide evidence based on the measures we considered most appropriate after consultation with stakeholders, but even these could be interpreted as having differing levels of success based on other targets. For example, previous research has indicated that reduced availability is unlikely to have an effect on smoking behaviour until TOD falls below a threshold density of around 1.5 retailers per square kilometre [4 per square mile: 26]. Several policies we tested reduce densities in the most deprived areas below this threshold and could therefore be considered more successful if that was a policy aim.

We have demonstrated that efforts to reduce tobacco availability for the whole population may further disadvantage some at-risk groups. The potential for such Intervention Generated

Inequalities (IGIs) has been well recognised with some arguing that those who would benefit most from particular interventions may be least likely to receive them [41]. Such outcomes may also transpire at an area level, in this case populations living in areas of the highest tobacco outlet availability, where smoking rates are also highest, may not benefit from any policy to reduce availability unless a specific equity lens is applied. Our results demonstrate that policies that optimise both *equity* and *density reduction* in tobacco control are possible. The appropriate weight to give equity targets has to be considered in the context of wider local and national strategies on health inequalities and priorities identified by key stakeholders and the public [42]. As we noted earlier in the paper, policy impacts are context dependent; the policies identified to be more equitable in Scotland may not be elsewhere. In this paper we explored inequalities by area-level deprivation, future analysis in other contexts may consider other demographic factors, such as ethnicity/race. Nevertheless, the range of policy options examined here provide a basis for exploring tobacco retail reduction elsewhere. Additionally, evidence is just one factor that influences policy change; legal, commercial and public support, along with real-world practicality are also necessary. Ackerman et al. (2017) provide a good overview of legal issues of enacting policies in a US context [16]. We intend this paper to be used as a guide for policymakers to understand the differential impacts of various policy opportunities so that they can consider which could be permittable, practical, and carry the necessary political and public support.

The strengths in this paper lie in evaluating the density reduction and equity of a range of potential policies. Previous studies have evaluated a single or small number of policies [17–19,21,22], and few have evaluated the equity impact [21,22]. We explicitly evaluated density reduction and equity-impact of twelve potential policies selected based on previous research, many of which have been considered elsewhere [19,21–24]. We used data on the real-world location of tobacco retailers to create continuous TOD surfaces as the basis for simulations, rather than hypothetical distributions at aggregate small area level. The main limitation is that we have only simulated the possible effects of policy on tobacco availability, rather than on smoking behaviour itself. The link between tobacco availability and smoking behaviour is largely based on correlational evidence [7], so we are unable to identify whether outlet density restrictions will lead to reduced smoking rates. Yet indirect increases to cost of tobacco products caused by reduced availability has been suggested as a mechanism through which smoking prevalence might be reduced [19,20,24]. Unfortunately, we were also not able to consider the impacts of legislating tobacco availability on the wider urban system, including the business models of small retailers, new retailers opening in low density areas to meet new demand, or the knock-on effects on illicit tobacco trade.

Conclusions

In this paper we address both overall reduction in tobacco retail provision by potential tobacco control policies from a population perspective, and equity-impact of outcomes for at-risk populations. Such an approach is essential if we wish to avoid intervention generated inequalities. Addressing the unfair and avoidable health inequities in areas of deprivation, including the availability of unhealthy commodities, is an important priority for policymakers. Using simulations, we examined the effectiveness of a range of potential policies at reducing inequities in tobacco retail environments. Our findings provide policymakers with new evidence for determining the appropriate policy approaches for addressing the key tobacco-related public health aims in their own jurisdictions.

What this study adds

- Reducing the availability of tobacco in the community has the potential to reduce both smoking related behaviours and health inequalities related to smoking related harms.
- This study explored 12 potential policy scenarios to reduce the availability of tobacco in communities, ranging from restricting the type of businesses licensed to sell tobacco to area level regulations on where tobacco can be sold.
- We tested each scenario for overall reduction in tobacco retail densities at the population level, and for equity-impact based on area-based inequalities in availability.
- We showed that measures that focus on the whole population may further disadvantage 'at risk' groups. However, we also showed that it is possible to reduce both overall population level availability whilst reducing area-level socioeconomic inequalities.
- Potential policies to reduce tobacco availability should address both overall impact and equity impacts of potential policy outcomes. Such an approach is essential if we wish to avoid intervention generated inequalities.

Contributions

Funding acquisition (NS, JP, RM, GR). Conceptualization (equal); Investigation (equal); Data curation & analysis (FC); Methodology (FC); Writing original draft (FC); Review & editing (equal); All authors read and approved the final manuscript.

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Table 1: Percent reduction in mean TOD across datazones, and percent reduction numbers of tobacco retailers nationally.

Policy	TOD	Retail number
Supermarket	86.4 (85.7--87.1)	94.6
Liquor store	85.9 (85.2--86.5)	94.1
Pharmacy	75 (73.4--76.5)	86.6
Reduce clusters	74.9 (74.1--75.7)	78.6
Child Spaces	72.9 (72.1--73.8)	70.7
Frequent purchases	69.6 (68.9--70.3)	69.3
Small local	58.4 (57.7--59.2)	57.0
Min Spacing	40.7 (40--41.5)	54.8
School	44.5 (43.6--45.4)	42.6
Cap Least Deprived	50.5 (49.8--51.3)	40.0
Cap Nat Av	35.6 (34.9--36.3)	32.3
On-Sales	15.4 (14.6--16.2)	23.9

Table 2: Equity-impact of tobacco control policies on mean TOD per 1,000 population per km^2 by area-level income deprivation. TOD in the most deprived quintile is given by the intercept of regressions fitted to mean densities across quintiles. TOD in the least deprived quintile is given as the intercept + 5 * SII. Policies are ranked by RII from highest (i.e. most inequality) to lowest. The level of socioeconomic inequality at baseline is shown in bold. Policies ranked above the baseline indicate increased levels of inequality, whereas those ranked beneath baseline indicate reduced inequality. P-values indicate statistical significance of the socioeconomic gradient, where non-significant values indicate that no significant inequality exists.

Policy	**TOD Most Deprived**	**TOD Least Deprived**	**SII**	**RII**	**P-value**
On-Sales	9.856	3.297	-1.312	2.990	0.000
Liquor store	0.964	0.325	-0.128	2.967	0.008
Pharmacy	1.776	0.625	-0.230	2.841	0.001
Baseline	**12.055**	**4.627**	**-1.486**	**2.605**	**0.000**
Minimum Spacing	4.247	1.700	-0.510	2.499	0.001
School	5.784	2.432	-0.670	2.378	0.000
Cap Least Deprived	3.805	1.615	-0.438	2.356	0.001
Cap National Av	5.396	2.320	-0.615	2.326	0.000
Child spaces	2.305	1.181	-0.225	1.952	0.004
Frequent purchases	3.231	1.674	-0.312	1.931	0.018
Small local	4.256	2.205	-0.410	1.930	0.016
Supermarket	0.541	0.285	-0.051	1.898	0.016
Reduce clusters	1.520	0.928	-0.118	1.638	0.067