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A longitudinal analysis of the impact of the local tobacco retail availability and neighbourhood deprivation on male smoking behaviours in Shanghai, China

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ABSTRACT

Some evidence from Western high-income countries suggests local tobacco retail availability and neighbourhood deprivation may influence smoking behaviours. However, this assertion has not been considered in China, where 44% of males continue to smoke. Data were analysed from Chinese males (n = 2054) who participated in Waves 3–5 (2009–2015) of the International Tobacco Control (ITC) China Survey by linking information on tobacco retail availability (estimated through population weighted Kernel Density of tobacco retailers in 2019) and neighbourhood deprivation (calculated as a composite score derived from the 2010 Chinese census) across Shanghai. Generalised Estimating Equation models were fitted to examine the impacts of local tobacco availability and neighbourhood deprivation on smoking behaviours (current smoking versus current non-smoking, quitting versus current smoking, longer durations of smoking abstinence versus current smoking) using the longitudinal data. Examining the impacts separately, participants living in neighbourhoods with greater availability and higher levels of deprivation were less likely to maintain longer durations of smoking abstinence in both unadjusted and adjusted models. Neighbourhood deprivation, but not availability, was found to be associated with higher odds of being a current smoker. Examining the impacts jointly, neighbourhood deprivation was still positively associated with current smoking and negatively associated with longer durations of smoking abstinence, but the negative association between availability and longer durations of smoking abstinence disappeared. The findings offer some evidence that greater tobacco retail availability and deprivation are obstacles on prolonged smoking cessation among males in Shanghai, China. Policymakers should consider small-area level place-based restrictions in China, such as reducing the availability of tobacco, as part of a comprehensive tobacco control strategy aimed at addressing the high prevalence of smoking.

1. Introduction

In China, with over 1 million smoking-attributable deaths each year, addressing the tobacco epidemic remains a major public health challenge (Xu et al., 2019; Parascandola and Xiao, 2019; Chen et al., 2015). China has achieved some recent successes in implementing tobacco control initiatives, such as the mass media anti-tobacco campaign (Sun et al., 2022), the tobacco advertising, promotion and sponsorship bans on national television, radio, and print media (Sun et al., 2022), the national tobacco sales ban around schools (China Tobacco, 2021), and the regional-level smoke-free policies (Sansone et al., 2019). Despite the modest reduction in smoking prevalence, 44.4% of men in China continue to smoke (GATS, 2018), additional steps should be taken to reduce smoking prevalence.

Increasing international evidence suggests that individual smoking behaviours could be influenced by a number of place-based characteristics (Pearce et al., 2012), such as neighbourhood deprivation or disadvantage (Fleischer et al., 2015b; Rachele et al., 2016; Lau et al., 2018; Morris et al., 2018), local availability of tobacco products (Cantrell et al., 2015; Marashi-Pour et al., 2015; Chaiton et al., 2018; Kong et al., 2021; Pearce et al., 2016), local social norms (Eisenberg et al., 2014; Stead et al., 2001; Karasek et al., 2012), social cohesion (Lin et al., 2012; Lozano et al., 2016; Fleischer et al., 2015a; Waring et al., 2020), neighbourhood disorder and perception of crimes (Shareck and Ellaway,

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2011; Fleischer et al., 2015a; Ellaway and Macintyre, 2009; Miles, 2006). From a policymaking perspective, specifying the local geographical processes shaping smoking practices provides opportunities for reducing smoking prevalence and smoking-related health inequalities (Pearce et al., 2016).

One local geographical characteristic that likely affects individual-level smoking is neighbourhood deprivation, which is linked to smoking through pathways including place-based practices (e.g. social capital, social norms, crime and stressors) and regulation/policy (e.g. local policies, tobacco availability) (Pearce et al., 2012). Previous research from high-income countries (HICs) suggests living in a more socioeconomically deprived neighbourhood is associated with higher levels of smoking (Halonen et al., 2016; Morris et al., 2018; Rachele et al., 2016) and a lower likelihood of quitting (Giskes et al., 2006; Turrell et al., 2012). However, research from other settings shows mixed results. In Mexico, the lower smoking intensity was found to be associated with higher-level neighbourhood deprivation, while quit attempts showed a U-shaped pattern (Fleischer et al., 2015b). Similarly, findings from South Africa suggest a non-linear relationship between neighbourhood deprivation and local-level smoking prevalence, with the highest prevalence among residents living in neighbourhoods with the middle range of the deprivation index (Lau et al., 2018). Limited research has studied the impact of neighbourhood deprivation on smoking in the context of China. Among the few studies in China, a longitudinal study across 235 communities (approximations of neighbourhoods) in 9 provinces found that neighbourhood social development, defined by indicators covering the provision of preschool education and treated water as well as the proportion of residential areas that lack of sanitation, was negatively associated with smoking frequency in 1991–2011 (Yang, 2017). A cross-sectional study using a more recent wave (2015) of the same survey (288 communities within 12 provinces) found neighbourhood deprivation was positively associated with smoking intensity (Chen and Kim, 2021). As a country with highly uneven regional socioeconomic development and limited progress with a comprehensive and effective approach to tobacco control, it is crucial to consider the impact of local neighbourhood deprivation.

Tobacco retail availability is another key neighbourhood characteristic that has been associated with smoking behaviours. Greater local availability of tobacco has been shown to contribute to tobacco consumption (Chuang et al., 2005; Lee et al., 2021; Lipperman-Kreda et al., 2012; Marsh et al., 2016), a higher likelihood of smoking initiation (Lipperman-Kreda et al., 2014; Marsh et al., 2016; Shortt et al., 2016; Cantrell et al., 2016) or continued smoking (Pearce et al., 2016; Shortt et al., 2016), and lower odds of cessation (Pearce et al., 2016; Cantrell et al., 2015; Chaiton et al., 2018; Reitzel et al., 2011) by reducing product costs and influencing social norms through providing more opportunities for obtaining products, raising brand awareness of tobacco products, and creating a competitive local retail market (Pearce et al., 2012). Most existing research in this area has been conducted in HICs. For example, in the US, greater neighbourhood availability of tobacco retailing was found to be associated with higher-level individual smoking (Chuang et al., 2005) and a lower likelihood of smoking cessation (Reitzel et al., 2011). Similarly, increased density of tobacco outlets was associated with decreased odds of intention to quit in high-income neighbourhoods of Canada (Chaiton et al., 2018). In New Zealand, residents living in neighbourhoods with better access to tobacco retailers were associated with higher odds of being smokers than those with poor access to tobacco retailers (Pearce et al., 2009). In Scotland, residents living in areas with the highest outlet densities were found to have higher odds of being current smokers and lower odds of being ex-smokers (Pearce et al., 2016). Other studies have used Global Positioning Systems and Geographical Information Systems to assess more precisely exposure (Caryl et al., 2019), including a study in the Netherlands which found that personalised assessment of tobacco retailer exposure was associated with pro-smoking cognitions amongst non-smoking adolescents (van Deelen et al., 2023). Further, modelling of the likely impacts of proposed policies to reduce the availability of tobacco retailing has shown the highly variable impact of different approaches on availability, equity and prevalence (Caryl et al., 2020; Hammond et al., 2020; Luke et al., 2017). It is also notable that most studies examining the effect of tobacco retail density on smoking behaviours use a cross-sectional framework while longitudinal assessments are still limited. In the context of China, evidence regarding the impact of neighbourhood-level tobacco retail density on individual smoking remains absent.

Enhancing our understanding of the influence of neighbourhood socio-commercial impacts on smoking behaviours is important for supporting the development of policies to address the tobacco epidemic and reducing tobacco-related inequalities between social groups (The U.S. Department of Health and Human Services, 2014), particularly in countries like China where the prevalence of smoking is extremely high. Under a transitional economy and rapid urbanisation, cities of China have experienced considerable changes in urban landscape (Li et al., 2013), social order and community structure (Shi et al., 2017; Shen, 2017), which may in turns to result in a transition in smoking patterns. Using a national representative sample from 1991 to 2004, Pan and Hu (2008a, b) reported no significant impact of community economic development stage on the probability of smoking and smoking frequency (Pan and Hu, 2008b) but neighbourhood deprivation was found to be associated with smoking frequency using the data in 2015 (Chen and Kim, 2021). Megacities like Shanghai are more advanced in this transformation and may share some similarities with what has been documented in HICs where residents living in neighbourhoods with better access to tobacco retailers and higher levels of neighbourhood deprivation may be more likely to smoke and less likely to quit (Pearce et al., 2016; Cantrell et al., 2015; Chaiton et al., 2018; Marsh et al., 2016; Halonen et al., 2016; Morris et al., 2018). Therefore, it is important to study the effects of tobacco retail availability and deprivation on smoking in Shanghai, one of the most populous megacities (24.2 million), with the most developed economy in the country and significant socio-spatial inequalities in tobacco retail availability (Zheng et al., 2022). The understanding of how neighbourhood socio-commercial environment affects smoking behaviours from Shanghai has the potential to not only inform policymaking aims for effective tobacco control in China's megacities but also offer useful insights for other cities from a long-term perspective. Therefore, this study uses longitudinal data from Shanghai to assess the impacts of neighbourhood-level socio--commercial characteristics including the availability of tobacco retail and deprivation on smoking-related behaviours.

2. Methods

2.1. Study samples

The study used data from the International Tobacco Control (ITC) China Survey, a population-based longitudinal survey in 12 cities of China, including Shanghai (Wu et al., 2010). Launched in 2006 (Wave 1), the survey used a stratified multistage cluster sampling design (Wu et al., 2010). Using the randomised probability proportional to population size sampling, 20 residential communities from 10 subdistricts were randomly chosen in each city (Wu et al., 2015). Within each selected residential community, adults from 300 households were approached and surveyed randomly until 40 smokers and 10 never-smokers were identified (Wu et al., 2015). Eventually obtaining a total sample of 800 adult smokers and 200 adult never-smokers across the city of Shanghai in Wave 1 (Wu et al., 2015). In the follow-up waves (Wave 2: 2007–2008, Wave 3: 2009, Wave 4: 2011–2012, and Wave 5: 2013–2015), respondents from the previous wave were contacted while the sample size for replenishment was determined based on the retention rates of the longitudinal samples (Wu et al., 2015). Respondents from new residential neighbourhoods/sub-districts were added following the framework of Wave 1 (Wu et al., 2015). The retention rate

for all respondents (smoker and non-smoker) in Shanghai were as follows: 90.1% (890 observations) in Wave 2, 79.6% (786 observations) in Wave 3, 56.8% (561 observations) in Wave 4, and 45.5% (450 observations) in Wave 5 (ITC China Research Team, 2017a).

To examine the neighbourhood effects on individual-level smoking, we used data from Waves 3–5 (2009–2015) since the contextual explanatory variables were only available for 2010 (deprivation) and 2019 (tobacco retail availability). The study sample for this study included respondents who had data for at least two waves, whereby 2420 respondents residing within 28 residential neighbourhoods of Shanghai were included. There is a large gender disparity in smoking prevalence in China (50.5% of men and 2.1% of women) (GATS, 2018). Although the ITC China Survey has tried to increase the sample size for women by surveying one male smoker and one female smoker from every selected household whenever possible (Wu et al., 2015), in Shanghai, the proportion of female current smokers constituted only 2.53% of the total sample across all five waves. Therefore, our study only focused on the neighbourhood effects on smoking among men, which left a total of 2054 male sample members (with 1356 male samples participated for 3 waves and 698 male samples participated for 2 waves). Characteristics of the study population are described in Table 1.

Table 1
Characteristics of study population (men only).

	Wave 3 (N = 589)	Wave 4 (N = 793)	Wave 5 (N = 672)	Cohort (N = 2054)
Smoking status, n (%)				
Never-smoker	423.32	534.41	462.23	1420.02
	(71.87)	(67.39)	(68.78)	(69.13)
Current smoker	156.60	241.96	179.95	577.89
	(26.58)	(30.51)	(26.78)	(28.14)
Quitter	9.08	16.63	29.82	56.09
	(1.54)	(2.10)	(4.44)	(2.74)
Quitter who has quit since the last wave	3.54 (0.60)	7.61 (0.96)	9.79 (1.46)	21.07 (1.03)
Age in years, mean (SE)	57.04	57.01	55.82	56.61
	(0.63)	(0.47)	(0.47)	(0.30)
Age group				
18-24	33.21	25.37	29.09	87.79
	(5.64)	(3.20)	(4.33)	(4.27)
25-39	28.91	33.97	22.99	85.65
	(4.91)	(4.28)	(3.42)	(4.17)
40-54	187.64	315.48	285.39	789.55
	(31.86)	(39.78)	(42.47)	(38.44)
55+	339.23	418.18	334.54	1091.02
	(57.89)	(52.73)	(49.78)	(53.12)
Levels of education, n (%)				
Low	209.57	230.83	162.00	600.94
	(35.58)	(29.11)	(224.11)	(29.26)
Medium	300.44	481.12	425.23	1207.89
	(51.01)	(60.67)	(63.28)	(58.81)
High	78.99	80.71	84.65	244.72
	(13.41)	(10.18)	(12.60)	(11.91)
NA	NA	0.34 (0.04)	0.12 (0.02)	0.45 (0.02)
Levels of household income per month, n (%)				
Low	236.20	126.31	146.18	508.68
	(40.10)	(15.93)	(21.75)	(24.77)
Medium low	223.18	286.47	98.01	602.74
	(37.89)	(36.12)	(14.59)	(29.34)
Medium high	58.76	117.42	119.49	296.60
	(9.98)	(14.81)	(17.78)	(14.44)
High	27.73	245.95	215.41	490.74
	(4.71)	(31.02)	(32.06)	(23.89)
NA	43.14	16.85	92.90	155.23
	(7.32)	(2.13)	(13.82)	(7.56)
Tobacco retail availability index, mean (SE)	18.62 (0.14)	19.43 (0.23)	19.71 (0.26)	19.30 (0.13)
Neighbourhood deprivation index, mean (SE)	−1.81 (0.07)	−1.46 (0.06)	−1.67 (0.07)	−1.63 (0.04)
Levels of urbanity				
Urban centre	213.94	236.67	219.85	670.76
	(36.32)	(29.85)	(32.72)	(32.66)
Urban area	375.06	556.33	452.15	1383.24
	(63.68)	(70.15)	(67.28)	(67.34)
Levels of deprivation				
Low	374.90	498.72	461.83	1336.71
	(63.65)	(62.89)	(68.73)	(65.08)
High	214.10	294.28	210.17	717.29
	(36.35)	(37.11)	(31.27)	(34.92)

2.2. Smoking status

Three measures of smoking status were calculated for each respondent to fully capture current and past smoking behaviour. The smoking status of each respondent was coded as smoker ("smoked cigarettes at least monthly and had smoked 100 or more cigarettes in their life time"), quitter ("smokers who had quit for a period of time "), and never-smoker when recruited, while the smoking status of re-contacted respondents was reviewed at each wave (ITC China Research Team, 2017a; ITC Data Management Core, 2019). Subsequently, quitters and never-smokers were grouped as current non-smokers to examine the neighbourhood effects on current smoking (versus current non-smoking). Quitting versus current smoking was specified to examine the impacts of availability and deprivation on smoking cessation. As quitting was further coded as 1) quitting for less than 1 month; 2) quitting for 1 to 6 months; 3) quitting for more than 6 months; and 4) quitting since the last wave, therefore, to identify whether the impacts may have an effect on a longer duration of smoking abstinence, quitting since the last wave versus current smoking was studied as well.

2.3. Tobacco retail availability

Neighbourhood-level availability of tobacco retailers was assessed using population-weighted Kernel Density Estimation (KDE). All validated tobacco retailers (n = 19,413) were geocoded based on the geo-coordinates of Points of Interest (POIs) data acquired from Baidu Online map through web-scraping in May 2019. The number and proximity of tobacco retailers were calculated across the city of Shanghai for 100 × 100m grids with a search radius of 10-min walking distance (800 m). The KDE value represents the smoothed density of tobacco retailers in Shanghai. Each residential community (avg. population = 5,888) is composed of several subcommunities (avg. population = 394). Overlaying the centroids of subcommunities onto the KDE surface, the corresponding values of KDE were extracted and weighted by the population size of each subcommunity (sourced from the 2010 Chinese census of Shanghai) to reflect the neighbourhood-level tobacco retail availability:

$$KDE_i = \frac{\sum_{j=1}^{n}\left(KDE_j \times pop_j\right)}{\sum_{j=1}^{n} pop_j}$$

where for each residential community i, KDE_i is the population-weighted KDE value (i.e. neighbourhood tobacco retail availability), n is the total number of subcommunities within each residential community, KDE_j and pop_j are the density value and population of the j th subcommunity within community i, therefore the population-weighted KDE of each neighbourhood represents the density of tobacco retailers per km^2 per neighbourhood (Zheng et al., 2022).

As a residential community-level measure, a higher availability index suggests better availability of tobacco retailers within residential neighbourhoods. Tobacco retail availability was treated as a continuous explanatory variable after mean centring.

2.4. Neighbourhood deprivation

Following prior studies in China, a neighbourhood-level deprivation score was calculated using the 2010 Chinese census at the residential community level measures combining data on 1) unemployment rate

(unemployed residents); 2) low-skilled workers rate (residents were blue-collar and pink-collar workers); 3) low-educational attainment rate (residents with junior high school education or below); and 4) non-home ownership rate (residents who are tenants). To be consistent with international indices such as the Carstairs and Townsend indices in the UK (Townsend et al., 1988), all census-based neighbourhood indicators were weighted equally and summed after standardising through z-score (Zheng et al., 2022). A higher score of neighbourhood deprivation indicates a higher level of neighbourhood deprivation. Neighbourhood deprivation indices were considered as a continuous explanatory variable.

2.5. Covariates

Potential factors that could confound the association between explanatory and outcome variables were controlled in the adjusted models. To reflect the key differentiations in smoking rates across the life-course, age was treated as a categorical variable (18–24, 25–39, 40–54, 55+). Education was categorised as 1) low (no education, elementary school, junior high school); 2) medium (high school and college); and 3) high (university or higher). Respondents' household income per month at each wave was standardised as 1) low (<3000 CNY); 2) medium-low (4000–4999 CNY); 3) medium-high (5000–6999 CNY); and 4) high (>7000 CNY). Missing values were included in the analysis as a separate category for each covariate.

Urbanity (urban centre versus urban area) was introduced as neighbourhood-level covariates for all outcome variables. Following previous work in Shanghai (Ouyang et al., 2017; Zheng et al., 2022), delineated by the structure of the road network, all neighbourhoods across Shanghai were classified as 'urban centre', 'urban area', and 'suburb'. The levels of urbanity decreased from urban centre neighbourhoods to urban area neighbourhoods, and to suburb neighbourhoods (Cui and Shi, 2012). Since the ITC Shanghai only surveyed residential communities in urban centre and urban areas of Shanghai, levels of urbanity were grouped as urban centre (n = 12) and urban area neighbourhoods (n = 16).

2.6. Statistical analysis

After linking tobacco retail availability and neighbourhood deprivation indices with survey data using the names of residential communities, descriptive statistics were applied to characterise variables of interest in study samples while Generalised Estimating Equation (GEE) with an exchangeable working correlation matrix was used to test the impacts of tobacco retail availability and neighbourhood deprivation on each outcome of interest over time separately.

GEE is able to estimate the population average effect by accounting for the nested structure of the data (Hubbard et al., 2010), where repeated measures on sociodemographics and behaviours across waves within individuals within residential communities. Specifically, four sets of models were conducted to test the impact of availability and deprivation on each outcome of interest over time. Model 1 (M1) tested the unadjusted association while individual-level covariates were controlled for Model 2 (M2). In Model 3 (M3), levels of urbanity were further controlled for the impact of availability (M3a) and deprivation (M3b) on each outcome of interest in addition to individual-level covariates. Finally, the joint effects of tobacco retail availability and deprivation on smoking behaviours were tested in Model 4 (M4), where only availability and deprivation were introduced into M4a, while individual covariates were further controlled in M4b. In M4c, in addition to individual-level covariates, levels of urbanity were controlled.

Additionally, a sensitivity analysis was performed among a larger sample of respondents; including the females who were excluded from the main study (see Appendices I-II). All statistical analyses were performed in Stata/IC 13. Sampling weights were accounted for descriptive and statistical analyses.

3. Results

3.1. Estimated population characteristics

Table 1 describes the estimated population characteristics by smoking status, individual-level socio-demographics, tobacco retail availability, and deprivation by applying sampling weights. For the cohort across Wave 3–5 (n = 2054), an estimated 28.14% of male respondents were current smokers, with 2.74% of the male respondents being quitters. Among all male samples, an estimation of 1.03% had quit since the last wave. The sample members had an average age of 56.61, with 53.12% of the male samples aged over 55 years old, slightly over half with median-level education (58.81%), and nearly a third with median low-level household income (29.34%). Among all male respondents, more than 60% of them lived in less urbanised neighbourhoods. Using the median deprivation score to define low and high neighbourhood deprivation, it was estimated that 65.08% of the male sample lived in less deprived neighbourhoods. Notably, to compare the study sample in each wave, the estimated proportion of quitters kept increasing from Wave 3 (1.54%) to Wave 4 (2.10%) to Wave 5 (4.44%) while the proportion of current smokers fluctuated, increasing from Wave 3 (26.58%) to Wave 4 (30.51%) but decreasing in Wave 5 (26.78%). The mean age of sample members kept decreasing from 57.04 (Wave 3) to 55.82 (Wave 5), the estimated proportion of sample members aged over 55 years was less than half (49.78%) in Wave 5 while it was 57.89% in Wave 3. The biggest proportion of levels of household income was low-level income in Wave 3 (40.10%), it was medium low-level in Wave 4 (36.12%), and high-level in Wave 5 (32.06%). The distribution of male respondents by levels of urbanity and deprivation showed fluctuations across three waves. Although the majority of the male samples lived in less urbanised neighbourhoods, the proportion of male respondents living in less urbanised neighbourhoods rose from 63.68% (Wave 3) to 70.15% (Wave 4), before slightly declining in Wave 5 to 67.28%. While the proportion of male respondents living in less deprived neighbourhoods decreased from 63.65% (Wave 3) to 62.89% (Wave 4) but increased to 68.73% in Wave 5.

3.2. Associations between availability, deprivation and each outcome of interest

Table 2 presents results from models for the main effects of availability and deprivation on each outcome of interest. In M1, which examined the unadjusted association between availability (M1a) and each outcome of interest, availability was significantly associated with reduced odds of longer duration of abstinence versus current smoking (OR (odds ratio) = 0.95, 95%CI (confidence interval) = 0.91, 0.99). Further, greater deprivation (M1b) was significantly associated with increased odds of current smoking versus current non-smoking (OR = 1.29, 95%CI = 1.07, 1.56) and reduced odds of longer durations of abstinence versus current smoking (OR = 0.76, 95%CI = 0.62, 0.92). After controlling for individual-level covariates (M2), the significant negative association between availability and longer durations of abstinence was still present (OR = 0.94, 95%CI = 0.90, 0.99) and the magnitude was strengthened slightly. The association between deprivation and current smoking (OR = 1.31, 95%CI = 1.08, 1.58) as well as the association between deprivation and longer durations of abstinence (OR = 0.78, 95%CI = 0.66, 0.92) remained significant after controlling for individual-level covariates. However, the strength of the association with current smoking increased, while it was weakened for longer durations of smoking cessation. In M3, levels of urbanity were introduced as a neighbourhood-level covariate (urban centre versus urban area) to adjust for the association between availability/deprivation and each outcome of interest, the significant association between availability and longer durations of smoking abstinence in M2a was still present in M3a (OR = 0.95, 95%CI = 0.90, 0.99), while the positive impact of neighbourhood deprivation on current smoking (OR = 1.31, 95%CI = 1.09,

Table 2
Associations between neighbourhood deprivation, availability and smoking behaviours.

	Current smoking (versus non-current smoking)	Quitting (versus current smoking)	Longer durations of abstinence (versus current smoking)
	OR (95% CI)	OR (95% CI)	OR (95% CI)
M1a. Availability	1.02 (0.98, 1.07)	1.00 (0.97, 1.02)	**0.95 (0.91, 0.99)****
M1b. Deprivation	**1.29 (1.07, 1.56)****	0.91 (0.80, 1.03)	**0.76 (0.62, 0.92)****
M2a. Availability	1.03 (0.98, 1.07)	0.99 (0.97, 1.02)	**0.94 (0.90, 0.99)***
M2b. Deprivation	**1.31 (1.08, 1.58)****	0.91 (0.81, 1.03)	**0.78 (0.66, 0.92)****
M3a. Availability	1.03 (0.98, 1.07)	1.00 (0.96, 1.04)	**0.95 (0.90, 0.99)***
M3b. Deprivation	**1.31 (1.09, 1.57)****	0.91 (0.81, 1.03)	**0.74 (0.60, 0.90)****
M4a. Availability	0.99 (0.95, 1.03)	1.01 (0.98, 1.05)	0.97 (0.91, 1.02)
Deprivation	**1.31 (1.09, 1.58)****	0.89 (0.75, 1.05)	**0.78 (0.62, 0.98)***
M4b. Availability	0.99 (0.95, 1.04)	1.00 (0.97, 1.04)	0.96 (0.91, 1.02)
Deprivation	**1.32 (1.09, 1.61)****	0.91 (0.77, 1.06)	**0.81 (0.66, 0.99)***
M4c. Availability	0.99 (0.94, 1.04)	1.02 (0.96, 1.07)	0.98 (0.91, 1.05)
Deprivation	**1.33 (1.08, 1.65)****	0.88 (0.73, 1.07)	**0.76 (0.59, 0.99)***

Note: CI=Confidence Interval; Statistical significance level: *0.05, **0.01, significant coefficients are also in bold.
M1 is the unadjusted model, tobacco retail availability (M1a) and neighbourhood deprivation (M1b) were included in the unadjusted model separately.
M2 examine the effects of tobacco retail availability (M2a) and neighbourhood deprivation (M2b) on each outcome of interest with the adjustment of individual-level covariates.
M3 examine the effects of tobacco retail availability (M3a) and neighbourhood deprivation (M3b) on each outcome of interest with the adjustment of levels of urbanity.
M4 examine the joint effects of tobacco retail availability and neighbourhood deprivation on each outcome of interest: only availability and deprivation were controlled in M4a, individual covariates were controlled in M4b, in addition to individual covariates and deprivation scores, levels of urbanity were further controlled in M4c.

1.57) and its negative impact on longer durations of abstinence (OR = 0.74, 95%CI = 0.60, 0.90) were both retained in M3b.

In M4, the significant associations between availability and longer durations of abstinence found in M1a, M2a and M3a were not apparent after controlling for area-level deprivation score. However, the statistical significance of the association between area-level deprivation and smoking behaviours was retained in M4, where greater magnitudes were found for current smoking (versus non-current smoking) but reduced magnitudes were found for longer durations of abstinence (versus current smoking).

The results of the sensitivity analyses, which included female study samples, were broadly consistent with those of the main study (Appendices I-II), there are no differences between the main study (Table 2) and sensitivity analyses (Appendix II). Specifically, in the full sample model, the association between availability/deprivation and longer durations of smoking abstinence remained unchanged, while the magnitude of the association between neighbourhood deprivation and current smoking was attenuated.

4. Discussion

This is the first study in China to examine the impacts of tobacco retail availability on a series of smoking behaviours based on a longitudinal research design. Using the male adult sample of ITC Shanghai, the biggest megacity of China, our study revealed that tobacco retail availability and neighbourhood deprivation may affect individual-level smoking behaviours: males living in neighbourhoods with higher availability of tobacco retailers are less likely to maintain longer durations of smoking abstinence. Males living in neighbourhoods with higher deprivation were more likely to smoke and less likely to quit for a longer duration. However, when simultaneously incorporating availability and deprivation into the model, significance can only be found between neighbourhood deprivation and smoking behaviours (current smoking versus non-current smoking and longer durations of cessation versus current smoking).

Our study used a cohort sample to identify the significant association between the availability of tobacco retailers and smoking cessation without and with the adjustment of individual covariates in the context of a megacity of China. Previous studies showed mixed results regarding the impact of availability on smoking cessation. Higher-level availability was found to be associated with a lower likelihood of quitting in Scotland (Pearce et al., 2016), but with no significant association found in England (Han et al., 2014). In the US, Retzeil et al. (2011) found negative impacts of availability on cessation while Kong et al. (2021) found this impact was non-significant. Our study demonstrated a significantly negative association between availability and longer durations of smoking abstinence across waves.

Although positive associations between availability and current smoking have been found in Scotland (Pearce et al., 2016), Australia (Marashi-Pour et al., 2015), and the US (Kong et al., 2021), our study did not find any meaningful results in the association between neighbourhood-level availability of tobacco retailers and the likelihood of current smoking in Shanghai. This could be due to the high overall prevalence of current smoking among the majority age group within the study population. According to the 2018 Global Adults Tobacco Survey (GATS), males aged 45–64 had the highest rates of current smoking, at 57.1%, followed by males aged 25–44 (53%) and males aged over 65 years (44%) (GATS, 2018). Given that the majority of our male respondents were over 40 years old, it is possible that they had long-standing smoking habits predating the survey enumeration, and thus local tobacco retail availability may not have a substantial impact on persistent smokers within this specific age group in terms of promoting current smoking.

The impact of neighbourhood deprivation on smoking behaviours is broadly consistent with previous findings from HICs such as Finland (Halonen et al., 2016), the UK (Morris et al., 2018) and Australia (Rachele et al., 2016; Turrell et al., 2012) that living in more deprived neighbourhoods was associated with a higher likelihood of current smoking and a lower likelihood of smoking cessation. Earlier work in China identified positive associations between neighbourhood deprivation and smoking intensity (Yang, 2017; Chen and Kim, 2021). Rather than smoking intensity, our work indicates that neighbourhood deprivation is capable of influencing current smoking and smoking cessation. Using a cohort of male samples, the findings on the impact of neighbourhood deprivation on current smoking versus non-current smoking and longer durations of smoking abstinence versus current smoking may provide more straightforward guidance for tobacco control policy-making than earlier findings regarding smoking intensity.

Although the significant association between local availability and smoking cessation became non-significant when examining the joint effects of tobacco retail availability and neighbourhood deprivation on smoking behaviours, this pattern may indicate that the area-level effect on smoking behaviours may be largely explained by neighbourhood deprivation, which has a much stronger impact than tobacco retail

availability. In addition, it is plausible that there were some underlying correlations between deprivation and individual covariates (Walters et al., 2004), as our area-level deprivation measure was calculated by aggregating individual data from the Census (i.e. education, employment, and occupation), while our individual covariates covered education and income from the survey. Moreover, as an even stronger association between neighbourhood deprivation and current smoking was captured in the joint effect model, the involvement of availability may strengthen the impact of neighbourhood deprivation on current smoking. The findings from the joint effect models suggest that the pathway of neighbourhood socio-commercial impacts affecting smoking behaviours is likely to be more complex than we expected, but neighbourhood deprivation has a direct and strong impact on smoking behaviours.

Some cities in China have implemented spatial restrictions to regulate the local availability of tobacco, including prohibiting tobacco sales around school areas (Guangzhou Tobacco Monopoly Bureau, 2021, Wushan Tobacco Monopoly Bureau of Chongqing, 2021, Shanghai Tobacco Monopoly Bureau, 2018, Haidian Tobacco Monopoly Bureau Of Beijing, 2021, Changsha Tobacco Monopoly Bureau, 2020; Hangzhou Tobacco Monopoly Bureau, 2021) and requiring a minimum distance between adjacent tobacco retailers (Wushan Tobacco Monopoly Bureau Of Chongqing, 2021; Haidian Tobacco Monopoly Bureau Of Beijing, 2021; Hangzhou Tobacco Monopoly Bureau, 2021). In Shanghai, by 2019, tobacco retail was prohibited within 50m of the main entrance of schools, with the aim of protecting adolescents from exposure to tobacco products and preventing smoking initiations. These place-based restrictions for tobacco retail have been proven to be an effective density reduction measure in Western high-income countries (Glasser and Roberts, 2020; Caryl et al., 2020), as well as in the context of Shanghai (Zheng et al., 2023). Our findings provide support for the enactment and enforcement of place-based tobacco control policies in China and suggest that more place-based tobacco control policies aimed at reducing the density of tobacco retailing is likely to reduce smoking prevalence.

There are some limitations to this study. First, the explanatory variables, including tobacco retail availability and neighbourhood deprivation, were acquired in a single period instead of being repeatedly measured over different years. The tobacco retail availability index was calculated using data from 2019, while the neighbourhood deprivation index was constructed using the Chinese census of 2010. The possible socioeconomic changes that happened especially within the less urbanised neighbourhoods of Shanghai were not able to be considered since the 2010 Chinese census remains the most recent census that is available for research use while the local area data from the 2020 Chinese census is not yet available. As our exposure variables are not repeated over time, our analysis might not represent the optimum longitudinal analysis. Nevertheless, our approach modelled the longitudinality by incorporating repeated measures of smoking behaviours into the analysis. In addition, as we are using data before 2020, our work might not be able to reflect the most up-to-date circumstances, as well as the impact of COVID-19. Due to data availability, our analysis can only focus on Shanghai, one of the most developed and wealthiest cities in China. However, as the city has a population of over 20 million, the evidence about the patterning of tobacco retail and smoking from Shanghai may provide useful insights for further development of tobacco control policies or initiatives, especially in other megacities in China. Future research could consider a full sample coverage from different cities in China when availability of tobacco retailers at a small area level is ready. Lastly, although all adjusted models were controlled for individual-level and neighbourhood-level covariates, residual confounding remains a possibility.

5. Conclusion

As a Party to the WHO Framework Convention on Tobacco Control, China is anticipated to implement stricter restrictions on tobacco retail to further control tobacco consumption. In the meantime, greater efforts in tobacco control are required to achieve the goal of reducing smoking prevalence and related health inequalities, which is one of the aims of Healthy China (2030); Goodchild and Zheng (2019). A series of smoke-free policies have been enforced for tobacco control in cities of China since 2008. However, place-based spatial restrictions on tobacco retail, which has been considered a new frontier in tobacco control (Cohen and Anglin, 2009), are still rare in the context of China. Countries including Netherlands (Nagelhout et al., 2023) and New Zealand (Marsh et al., 2022; Graham-DeMello and Hoek, 2023) have national plans in place to restrict the number of retailers selling tobacco products. As these plans are implemented, it will be important to assess the efficacy of the approaches taken to reduce availability and to understand the impact on smoking initiation, cessation and prevalence amongst different demographic, social and ethnic groups.

Our study demonstrates the negative impacts of tobacco retail availability and neighbourhood deprivation on smoking cessation and the positive impact of neighbourhood deprivation on current smoking in the context of Shanghai, China. We suggest that local policymakers should consider implementing comprehensive tobacco control strategies at the neighbourhood level. In addition to conventional individual-level tobacco interventions, regulating tobacco retail at the neighbourhood level remains an opportunity to encourage smoking cessation.

Each local Tobacco Monopoly Bureau (TMB) in China has the authority to design and enforce regulations regarding tobacco retail and tobacco control under national-level guidelines. The case of Shanghai provides useful insights into how neighbourhood-level processes affect smoking in a megacity context, which can help in designing regional/city-level effective spatial restrictions for further tobacco control, especially for megacities of China.

Ethics

The survey protocols and all materials, including the survey questionnaires, were cleared for ethics by the Research Ethics Board, University of Waterloo, Canada (REB#12539, REB#15305, REB#17014/30105; Cancer Council Victoria, International Review Board, Australia (IER0803); Chinese Center for Disease Control and Prevention International Review Board, China (IRB201114 and IRB201325). Secondary data analysis ethics clearance was received from Research Ethics and Integrity Committee, The University of Edinburgh (2020-431).

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CRediT authorship contribution statement

Chunyu Zheng: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Zhiqiang Feng:** Conceptualization, Data curation, Methodology, Supervision, Writing – review & editing. **Jamie Pearce:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2023.103171.

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