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**Socio-spatial inequalities in tobacco retail
availability and smoking in megacities of China,
a case study of Shanghai**

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Thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy to the University of Edinburgh

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Declaration

I declare that this thesis has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where states otherwise by reference or acknowledgement, the work presented is entirely my own.

The work presented in Chapter 4 was previously published in the peer-reviewed journal *Nicotine and Tobacco Research* as *A Cross-sectional Analysis of Socio-spatial Patterning of Tobacco Retail in Shanghai, China* by Chunyu Zheng, Zhiqiang Feng, and Jamie Pearce. This study was conceived by all of the authors. I carried out data collection, performed data analysis, and wrote the manuscript in consultation with Zhiqiang Feng and Jamie Pearce.

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Abstract

Background. China is the world's biggest manufacturer and consumer of tobacco products. In 2019, the smoking prevalence was 26.6%, with a large gender disparity (50.5% of men and 2.1% of women). Over 1 million deaths and an estimate of USD 45.28 billion in health expenditure could be attributed to tobacco smoking (2015). Aiming to reduce the national-level smoking prevalence by 20% along with a reduction in health inequalities, *Healthy China 2030* was proposed in 2016 as a national strategy, which makes the tobacco epidemic a public health priority in China. Increasing international evidence suggests tobacco retail availability is associated with smoking, with more tobacco retailers clustered within more vulnerable areas. Regulating tobacco retail availability provides policy opportunities for effective tobacco control. However, the evidence in this area is scarce in the Chinese context. Therefore, the aim of this thesis is to investigate the socio-spatial inequalities in tobacco retail availability and smoking behaviours in the context of Shanghai, the biggest megacity of China with the most developed economy and a well-established local tobacco retail market in a transition economy and rapid urbanisation.

Methods. This thesis comprises of four related empirical studies using multiple datasets. Using web-based Points of Interest data (POIs) regarding tobacco retailers (2019) and the neighbourhood deprivation index constructed by the 2010 Chinese census, population-weighted kernel density estimation, the Kruskal-Wallis test and effect size estimation were utilised for Study 1 to examine the socio-spatial disparities of tobacco retail availability and its association with neighbourhood deprivation. Study 2 used registered public school data (2019) and POIs regarding tobacco retailers, along with the neighbourhood deprivation index, to investigate whether and to what extent tobacco retailers cluster around public schools, as well as the compliance of tobacco retailers with local spatial restrictions through spatial analysis techniques (i.e. network analysis and multi-distance spatial cluster analysis). Linking tobacco retail availability index and neighbourhood deprivation index with the International Tobacco Control China Survey (2009-2015), Study 3 used 2-level logistic regression and generalised estimating equations to determine the cross-sectional and longitudinal relationship between tobacco retail availability, neighbourhood deprivation, and smoking

behaviours. Study 4 simulated a total of 12 key-stakeholder-informed scenarios. It used spatial analysis techniques to evaluate the impacts of plausible spatial restrictions on tobacco retail availability reduction.

Results. Study 1 suggests the overall tobacco retail availability in Shanghai was high (9.50 retailers per km² per neighbourhood), with a significant non-linear association between tobacco retail availability and neighbourhood deprivation, which further varied across levels of urbanity ($p < 0.001$), as well as the widespread availability of convenience stores. Study 2 revealed a significant spatial clustering of tobacco retailers around public schools, with 95.8% of public schools being exposed to tobacco retail and 60.1% of tobacco retailers in the vicinity of a public school within an 800 m distance. Additionally, about 5.9% of public schools were exposed to non-compliant tobacco retailers. Study 3 suggests that tobacco retail availability and neighbourhood deprivation were each significantly associated with individual-level smoking, and their impacts differed in cross-sectional and longitudinal models. Furthermore, the association between tobacco retail availability and individual-level smoking varied by urbanity and deprivation level. Study 4 indicates all spatial restrictions have the potential to reduce tobacco retail availability substantially, but the most effective restriction may greatly increase social inequality in tobacco retail availability. In addition, the impacts of spatial restrictions on reducing tobacco retail availability and inequality differed by urbanity level.

Conclusion. Findings revealed the existence of socio-spatial inequalities in tobacco retail availability and smoking in the context of Shanghai, which calls for the development of a comprehensive tobacco control strategy. This thesis provides useful insights into regulating tobacco retail availability, which remains an opportunity for effective tobacco control. In addition to reducing overall availability, regulating availability at the neighbourhood level and focusing on retailer type in the process of tobacco retail licensing could be effective for the completion of tobacco control strategies. Furthermore, stricter restrictions on tobacco retail should be considered around school areas. Moreover, while spatial restrictions could reduce tobacco retail availability substantially, the most effective restrictions may actually increase

inequality in tobacco retail availability. It is critical for policymakers to enact policies targeting different social groups and groups in certain geographical areas.

Lay Summary

In China, tobacco use resulted in over 1 million deaths and USD 45.28 billion in healthcare costs in 2015. If the current trends continue, the enormous burden of tobacco use will keep rising. *Healthy China 2030*, a national strategy proposed in 2016, aims to reduce national-level smoking prevalence by 20%, indicating tobacco control has become a public health priority, and the initiation of effective tobacco control strategies has been placed on the agenda. In western high-income countries, individuals residing in more disadvantaged neighbourhoods may be exposed to greater densities of tobacco retail, have higher odds of smoking/smoking initiation, and are less likely to quit, but little is known in the Chinese context, where China is the biggest tobacco producer and has the largest smoking population. This work examined whether tobacco retailers are more available in some neighbourhoods, how neighbourhood environments (such as deprivation and access to tobacco retailers) affect smoking behaviours, and how policies can restrict access to tobacco retailers using a case study in Shanghai, the largest megacity in China with the most developed economy.

According to the first study, the distribution of tobacco retailers within neighbourhoods was inequitable across the metropolitan area of Shanghai; people living in urban centre neighbourhoods and in medium-deprived neighbourhoods had easier access to tobacco retailers. Among different types of tobacco retailers, convenience stores were the most common type, while the relationship between the availability of tobacco retail and neighbourhood deprivation was stronger in tobacco-only outlets than in convenience stores and supermarkets.

The results of the second study showed that over half of the tobacco retailers in Shanghai were allocated around public schools within walking distance. Furthermore, there was evidence that tobacco retailers were clustered around public schools spatially. In examining the compliance of tobacco retailers with the spatial restriction, which prohibits tobacco sales around schools within 50 metres of the main entrance, most tobacco retailers complied.

The third study indicated neighbourhood characteristics, including deprivation and access to tobacco retailers, were linked to smoking behaviours using a cohort of male samples in Shanghai. When individual data were examined at a single point in time, males living in neighbourhoods with easier access to tobacco retailers were more likely to smoke, whereas males living in neighbourhoods with higher levels of deprivation were more likely to smoke and less likely to quit. Examining multiple waves of individual data, we discovered that males who lived in neighbourhoods with easier access to tobacco retailers and in areas with higher levels of deprivation were less likely to quit over time.

The fourth study explored how various spatial restrictions may affect the availability of tobacco retailers. Findings revealed that all spatial restrictions can considerably reduce the availability of tobacco retailers. Among all types of spatial restrictions, requiring a minimum distance between two neighbouring tobacco retailers and prohibiting tobacco sales around schools had better performance in constraining the availability of tobacco retailers. Further examining whether these spatial restrictions can help reduce the existing social inequality in accessing tobacco retailers revealed that not all spatial restrictions are capable of reducing inequality. Compared with the real situation in Shanghai in 2019, the social inequality in access to tobacco retailers increased greatly after requiring a minimum distance, whereas prohibiting tobacco sales around schools substantially reduced the social inequality in accessing tobacco retailers.

This work can narrow the knowledge gap by enhancing the understanding of the characteristics of the local tobacco retail environment, its relationship with smoking behaviours, and the policy impact on tobacco retail in China. In addition, this work can offer critical insights for effective tobacco control in Chinese cities. It is critical to enact comprehensive tobacco control strategies whereby constraining access to tobacco retailers remains great potential for effective tobacco control. Furthermore, based on the established tobacco licensing system in China, stricter spatial restrictions aimed at regulating the availability of tobacco retailers should be considered. Also, policymakers and administrators should have a particular focus on the types of tobacco retailers in the process of developing spatial restrictions and tobacco retail licensing.

Finally, local policymakers and administrators should be aware that people may be exposed to easier access to tobacco retailers in some neighbourhoods, and specific spatial restrictions may have a larger impact on certain groups of people. Policies targeted at specific social groups or residents of particular areas may better facilitate effective tobacco control.

Abbreviations

CDC, Center for Disease Control and Prevention;

CI, confidence interval;

CNTC, China National Tobacco Corporation;

COPD, chronic obstructive pulmonary diseases;

GATS, Global Adult Tobacco Survey;

GEE, Generalised Estimating Equation;

GIS, Geographic Information System;

GPS, Global Positioning System;

GAQSIQ, General Administration of Quality Supervision Inspection and Quarantine;

GYTS, Global Youth Tobacco Survey;

FCTC, Framework Convention on Tobacco Control;

HICs, high-income countries;

ICM, Implementation Coordination Mechanism;

ITC, International Tobacco Control Survey;

KDE, Kernel Density Estimation;

LMICs, low- and middle-income countries;

LLMICs, low- and lower-middle-income countries;

MICs, middle-income countries;

MLM, multilevel modelling;

MOF, Ministry of Finance;

MOFA, Ministry of Foreign Affairs;

MOH, Ministry of Health;

MOIIT, Ministry of Industry and Information Technology;

NCD, non-communicable disease;

NPC, National People's Congress;

OR, odds ratio;

POIs, Points of interest;

SAIC, State Administration for Industry and Commerce;

SES, socioeconomic status;

STMA, State Tobacco Monopoly Administration;

TMB, Tobacco Monopoly Bureau;

TML, Tobacco Monopoly Law;

UMICs, upper middle-income countries;

UK, United Kingdom;

US, United States;

WHO, World Health Organization.

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Table of Contents

Abstract.....	III
Lay Summary	VI
Abbreviations.....	IX
Acknowledgements.....	XI
Table of Contents	XII
List of Figures.....	XVII
List of Tables.....	XVIII
Chapter 1 Introduction	1
1.1 Health Hazard of Tobacco Smoking	2
1.1.1 Global burden of tobacco epidemic	2
1.1.2 Tobacco smoking in China	3
1.2 Progress in Tobacco Control	6
1.2.1 Global progress in tobacco control	6
1.2.2 Tobacco control in China.....	7
1.3 Policy Environment of Tobacco Retail	12
1.3.1 Global practice in tobacco retail licensing.....	12
1.3.2 Tobacco retail licensing in China	12
1.4 Geographical Approach to Smoking	14
1.5 Problem Statement.....	15
1.5.1 Why Shanghai.....	15
1.5.2 Conceptual framework.....	16
1.6 Aims and Research Questions	18
1.7 Thesis Structure	19
1.8 References	21
Chapter 2 A narrative review on neighbourhood effects, tobacco retail availability, and smoking.....	27
2.1 Neighbourhood Effects on Smoking	28
2.1.1 Pathways of neighbourhood effects on smoking	28
2.1.2 Individual characteristics in relation to smoking	31
2.1.3 Neighbourhood characteristics in relation to smoking	35
2.1.4 Evidence from China	38
2.2 Tobacco Retail and Smoking.....	44

2.2.1 Pathways linking tobacco retail and smoking	44
2.2.2 Socio-spatial differences in tobacco retail availability	44
2.2.3 Tobacco retail availability and smoking	46
2.2.4 Evidence from China	49
2.3 Regulating tobacco retail and smoking	53
2.3.1 Spatial restrictions for regulating tobacco retail	53
2.3.2 The effectiveness of spatial restrictions	53
2.3.3 Equity impact of spatial restrictions	55
2.3.4 Spatial restrictions for regulating tobacco retail in China	57
2.4 Conclusions: neighbourhood-level evidence from Chinese context	59
2.5 References	60
Chapter 3 Data and methods	77
3.1 Study Setting	78
3.2 Data	80
3.2.1. Web-based data	80
3.2.2 Administrative data	82
3.2.3 Longitudinal survey data - Individual data	86
3.3 Spatial Analysis	89
3.3.1 Kernel density estimation (KDE)	89
3.3.2 Network analysis	90
3.3.3 Spatial cluster analysis	91
3.3.4 Spatial thinning	91
3.4 Statistical Analysis	93
3.4.1 Kruskal-Wallis test	93
3.4.2 Effect size estimation	94
3.4.3 Two-level logistic regressions	94
3.4.4 Generalised estimating equations	95
3.5 Analytic Strategy	97
3.6 References	100
Chapter 4 A cross-sectional analysis of socio-spatial patterning of tobacco retail in Shanghai, China	105
4.1 Abstract	106
4.2 Introduction	108
4.3 Methods	111

4.3.1. Study setting.....	111
4.3.2. Tobacco retailer data.....	111
4.3.3 Neighbourhood deprivation	113
4.3.4 GIS spatial analysis.....	113
4.3.5 Statistical analyses	114
4.4 Results	116
4.4.1. Spatial distribution of tobacco retail availability	116
4.4.2 Neighbourhood deprivation and tobacco retail availability.....	116
4.4.3 Socio-spatial disparities by tobacco retailer type.....	118
4.5 Discussion.....	120
4.5.1 Summary of findings.....	120
4.5.2 Interpretations of key findings	120
4.5.3 Limitations	122
4.6 Conclusion	123
4.7 References	124
4.8 Supplementary Materials.....	128
Chapter 5 A spatial analysis of the tobacco retail environment around public schools in Shanghai, China.....	137
5.1 Abstract.....	138
5.2 Introduction	140
5.3 Methods	143
5.3.1 Data.....	143
5.3.2 Analyses.....	144
5.4 Results	146
5.4.1 The distribution of tobacco retailers around all public schools	147
5.4.2 The distribution of tobacco retailers around each public school	148
5.4.3 Spatial clustering of tobacco retailers around public schools.....	149
5.4.4 Retailer compliance with spatial restrictions	150
5.5 Discussion.....	152
5.5.1 Summary of findings.....	152
5.5.2 Interpretation of key findings.....	152
5.5.3 Limitations	154
5.6 Conclusion	155
5.7 References	156

5.8 Supplementary Materials: Construct School Deprivation Index.....	161
Chapter 6 A cross-sectional and longitudinal analysis of neighbourhood effects of tobacco retail availability and neighbourhood deprivation on smoking behaviours among men in Shanghai, China	165
6.1 Abstract	166
6.2 Introduction	167
6.3 Methods	170
6.3.1 Study Samples.....	170
6.3.2 Measures	171
6.3.3 Statistical Analysis.....	173
6.4 Results	175
6.4.1 Sample characteristics.....	175
6.4.2 Cross-sectional models	175
6.4.3 Longitudinal models	176
6.4.4 Stratified models	176
6.4.5 Time-varying model	177
6.4.6 Sensitivity analysis	177
6.5 Discussion	182
6.5.1 Summary of key findings.....	182
6.5.2 Interpretation of key findings	182
6.5.3 Limitations	184
6.6 Conclusion.....	185
6.7 References	186
6.8 Supplementary Materials.....	190
Chapter 7 The potential impacts of spatial restrictions on tobacco retail provision in China: a simulation study in Shanghai.....	196
7.1 Abstract	197
7.2 Introduction	198
7.3 Methods	201
7.3.1 Baseline.....	201
7.3.2 Neighbourhood deprivation	201
7.3.3 Simulation scenarios	202
7.3.4 Measuring tobacco retail availability.....	202
7.3.5 Analyses.....	203

7.4 Results	206
7.4.1 Tobacco retail availability reduction	206
7.4.2 Equity impact	209
7.5 Discussion.....	213
7.5.1 Summary of findings.....	213
7.5.2 Interpretations of key findings	213
7.5.3 Limitations	215
7.6 Conclusion	217
7.7 References	218
7.8 Supplementary Materials.....	223
Chapter 8 Conclusions	225
8.1 Summary of key findings	226
8.2 Contribution to theories	229
8.2.1 Socio-spatial disparities in tobacco retail availability	229
8.2.2 Neighbourhood effects on smoking	231
8.2.3 Place-based policies and local tobacco retail market.....	232
8.3 Strengths, Limitations, and Future Perspectives	233
8.3.1 Strengths	233
8.3.2 Limitations	235
8.3.3 Future perspectives	236
8.4 Policy Implications	239
8.5 Conclusions	242
8.6 References	243

List of Figures

Figure 1.1 Smoking prevalence by age group, GATS China 2010 and 2018	3
Figure 1.2 Smoking prevalence by gender, GATS China 2010 and 2018	3
Figure 1.3 The parallel administrative structure of the tobacco industry in China	7
Figure 1.4 The organising institutions of the Inter-Ministry Implementation Coordination Mechanism (ICM) for WHO FCTC implementation in China	9
Figure 1.5 Tobacco retailers in Shanghai	15
Figure 1.6 Conceptual framework on how local-level policy and neighbourhood environments affect individual-level smoking behaviours	17
Figure 3.1 Administrative division of Shanghai at the residential community level	78
Figure 3.2 The metropolitan area of Shanghai by urbanity level	79
Figure 3.3 Illustration on network-based service area analysis	90
Figure 3.4 Analytic strategy in Chapter 4	97
Figure 3.5 Analytic strategy in Chapter 5	98
Figure 3.6 Analytic strategy in Chapter 6	98
Figure 3.7 Analytic strategy in Chapter 7	99
Figure 4.1 The overall association between neighbourhood deprivation quintiles and tobacco retail availability	117
Figure 4.2 The association between neighbourhood deprivation quintiles and tobacco retail availability by 3-level urban classification	117
Figure 5.1 Spatial distribution of tobacco retailers and public schools	146
Figure 5.2 The potential bias in examining the compliance of tobacco retailers with spatial restrictions for tobacco retail	154
Figure 7.1 The reduction rate by count of tobacco retailers across the city and by urbanity level	207
Figure 7.2 Tobacco retail availability reduction across the city and by urbanity level	208
Figure 7.3 Tobacco retail availability reduction by deprivation quintile across the city and urbanity level	212

List of Tables

Table 1.1 Cost-effective measures in the MPOWER package	6
Table 1.2 Assessment on achievement in implementing MPOWER measures in China, 2021	10
Table 2.1 Pathways of neighbourhood effects on smoking.....	29
Table 2.2 A summary of previous important evidence from China	41
Table 2.3 Major types of spatial restrictions for regulating tobacco retail.....	53
Table 2.4 Spatial restrictions aimed at reducing tobacco retail availability in HICs	53
Table 2.5 A summary of previous studies that examined the effectiveness of spatial restrictions	54
Table 2.6 Enforced spatial restrictions in some megacities of China.....	57
Table 3.1 Types of data and the corresponding chapter	80
Table 3.2 The categories of Baidu POIs.....	81
Table 3.3 Types of roads (“highway”) in OSM.....	82
Table 3.4 Education system and the corresponding public school types in Shanghai	83
Table 3.5 Items included in the 2010 Chinses census	84
Table 3.6 Descriptive statistics on census variables about residential community-level housing conditions by levels of urbanity and across Shanghai	85
Table 3.7 Comparison of established deprivation indices.....	86
Table 3.8 Census data to deprivation index.....	86
Table 3.9 An overview of ITC China	87
Table 3.10 Sample size of ITC China Wave 1-5 in Shanghai	87
Table 3.11 Individual-level variables drawn from the ITC China	88
Table 3.12 Statistical analysis and the corresponding chapter	93
Table 4.1 Distribution of population-weighted KDE of tobacco retailers	116
Table 4.2 Median population-weighted KDE by types of tobacco retailers and neighbourhood deprivation quintiles by across the city, urban centre and suburb ..	118
Table 5.1 Number (%) of all tobacco retailers within 400 m and 800 m of schools by types of school, levels of urbanity and deprivation, and types of tobacco retailer ..	147
Table 5.2 Median (min, max) of tobacco retailers around the main entrance of each public school by types of schools, levels of urbanity and school deprivation, and types of tobacco retailers.....	148
Table 5.3 Ratios of K-function from the main entrance of public schools	150
Table 5.4 Proportion (%) of public schools in vicinity of tobacco retailers.....	151
Table 6.1 Characteristics of study population (men only).....	178
Table 6.2 Cross-sectional associations between tobacco retail availability, neighbourhood deprivation and smoking behaviours (men only).....	179
Table 6.3 Longitudinal associations between tobacco retail availability, neighbourhood deprivation and smoking behaviours (men only).....	180
Table 6.4 The association between tobacco retail availability and smoking behaviours adjusted through wave indicator (men only)	181
Table 7.1 Constructing simulation scenarios.....	205

Table 7.2 Tobacco retail availability by neighbourhood deprivation quintiles across the city and by urbanity level 211

Chapter 1 Introduction

1.1 Health Hazard of Tobacco Smoking

1.1.1 Global burden of tobacco epidemic

The tobacco epidemic is one of the biggest global public health challenges,¹ accounting for approximately 5-6 million annual deaths² and an annual expenditure of over USD 1 trillion.³⁻⁵ Despite the reduction in age-standardised global smoking prevalence since 1990 (-27.5% of men and -37.7% of women), there were still more than 1 billion current smokers globally (32.7% of men and 6.62% of women) in 2019.⁵ Notably, the majority of tobacco users (80%) living in low- and middle-income countries where the burden of tobacco-related mortality and morbidity is heaviest.¹ Comprising about 67% of the global smoking population, China, India, Indonesia, the USA, Russia, Bangladesh, Japan, Turkey, Vietnam, and the Philippines are the countries with the largest number of smokers.⁵ There is a gap in smoking prevalence between low-and middle-income countries and high-income countries. About 49% of men and 8% of women were current smokers in low- and middle-income countries, whereas it was 37% of men and 21% of women in high-income countries.^{2, 6}

Smoking is a major behavioural risk factor common to major non-communicable diseases (NCDs).⁷ In 2019, smoking was responsible for 13.6% (7.69 million) of all-cause-deaths and 7.89% (200 million) of all disability-adjusted life years (DALYs).⁵ With the significant gender disparities, tobacco smoking accounted for 20.2% of all-cause deaths among males, whereas it was 5.84% among females.^{3, 5} Specifically, 77.5% (5.96 million) of smoking-attributable deaths occurred in low- and middle-income countries.⁵ If current smoking patterns remain, the number of global smoking-attributable deaths will rise to approximately 10 million annually by 2030.^{2, 8, 9} The establishment and enforcement of effective tobacco control policies and interventions has been identified as a critical and essential priority in order to reduce the prevalence of tobacco use, and the premature mortality caused by NCDs that can be attributed to tobacco smoking, as well as the damaging economic consequences of tobacco smoking.^{5, 8}

1.1.2 Tobacco smoking in China

China is the world's largest manufacturer and consumer of tobacco,¹⁰ with about 341 million (30%) of the 1.14 billion global smoking population in 2019.⁵ Peaked in 1996 (35.3%),^{11, 12} the smoking prevalence in China decreased to 28.1% (2010)¹³ and to 27.77% (2015).^{11, 12} According to the Global Adult Tobacco Survey (GATS),^{13, 14} Figure 1.1 illustrates the smoking prevalence in China by age group in 2010 and 2018. Although the overall smoking prevalence decreased slightly, the smoking prevalence among those aged 15-24 years increased from 17.9% to 18.6%.¹⁴

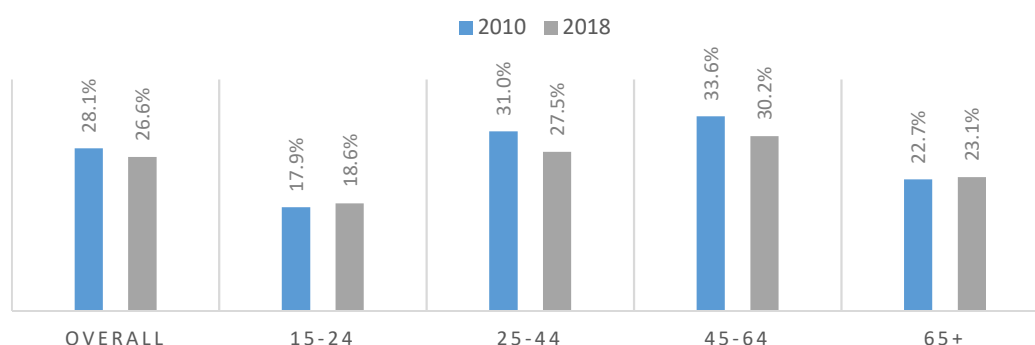


Figure 1.1 Smoking prevalence by age group, GATS China 2010 and 2018. Data were derived from China CDC (2018)¹⁴

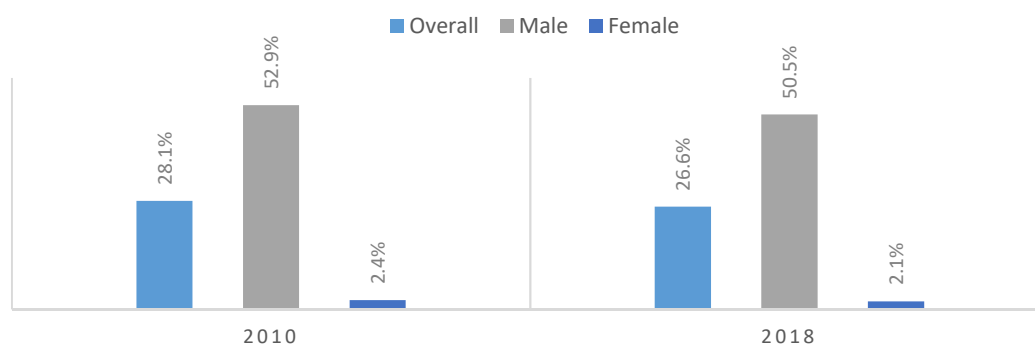


Figure 1.2 Smoking prevalence by gender, GATS China 2010 and 2018. Data were derived from China CDC (2018)¹⁴

The smoking prevalence showed significant gender disparities in China. Sourced from the GATS, Figure 1.2 shows significant disparities in smoking prevalence by sex in 2010 and 2018. Since 2010, the smoking prevalence for both sexes has reduced, with

-2.4% among males and -0.3% among females. A similar result was found from the Global Burden of Diseases Study 2019 (GBD 2019), which found that the smoking prevalence in China was 49.7% among males and 3.54% among women.⁵ The significant gender differences were retained even though the smoking prevalence showed a reduction for both sexes (-18.2% among males and -20.9% among females) since 2009.⁵

In addition to the differences in smoking prevalence by age and sex, geographical differences in smoking prevalence existed within China at the provincial-level.¹⁵ Across 2003-2013, the provincial-level smoking prevalence ranged from 15.4% (Xinjiang) to 35.9% (Inner Mongolia) in 2003, ranging from 14.7% (Xinjiang) to 32.9% (Guizhou) in 2008, and 16.2% (Xinjiang) to 34.6% (Guizhou) in 2013.¹⁵ Using different data but both collected in 2011, Yang et al. (2015) and Lee et al. (2019) suggested a lower smoking prevalence was found in the eastern coast,^{16, 17} notably in Shanghai (21.6%).¹⁶ However, Yang et al. (2015) indicated provinces with higher-level cigarette production were associated with greater smoking prevalence, with the highest smoking prevalence in western provinces (e.g. Yinchuan, Ningxia, Inner Mongolia) and in some southern provinces (e.g. Guizhou and Guangdong),¹⁶ while Lee et al. (2019) suggested northern provinces had a higher prevalence of smoking, with no significant differences found in the northeast and the southern provinces.^{17, 18} While individual socioeconomic status has been related to smoking, area income, such as urban GDP per capita or urban disposable income per household, was not found to be associated with smoking prevalence.¹⁶

China is facing an immense public health challenge in tobacco-attributable diseases,^{19, 20} along with the associated economic burden. Although smoking prevalence is currently decreasing in China,²⁰ there is a significant rise in smoking-attributable morbidity and mortality.⁵ Approximately 16.5% (1.4 million) of all deaths were attributed to tobacco smoking in 2010,^{21, 22} while this rate increased to 22.7%²³ (2.4 million) in 2019.⁵ The GBD 2019 study suggested China is the country with the largest absolute increase in the number of smoking-attributable deaths in 1990-2009.⁵ The risks of smoking-attributed NCDs were higher among ever-smokers than non-smokers, with an increased risk associated with early smoking initiation.¹⁵ The risks of smoking-

attributed NCDs, including peptic ulcer, trachea or lung cancer, chronic obstructive pulmonary diseases (COPD), and dental diseases, were highest for both sexes.¹⁵ The number of tobacco-attributed deaths in China will keep rising if the current smoking pattern remains.²⁴ Not to mention the tobacco-attributable healthcare expenditure, which has risen from USD 28.9 billion (2008)²⁵ to USD 45.28 billion (2015).²⁶

1.2 Progress in Tobacco Control

1.2.1 Global progress in tobacco control

The health and economic tragedy imposed by tobacco is preventable through implementing and enforcing effective tobacco control policies and interventions.^{1, 5, 8} Coming into force in 2005,⁵ in response to the global tobacco epidemics,^{27, 28} with 182 parties,⁵ the WHO Framework Convention on Tobacco Control (FCTC) is the first international binding public health treaty that outlines a suite of recommended demand-reduction strategies,^{5, 28} including taxation, smoke-free laws, mandating health, package warnings, and banning tobacco advertising, promotion, and sponsorship.^{27, 28} Further in 2008, WHO introduced the MPOWER package (Table 1.1) to support the implementation of the FCTC.^{29, 30}

Table 1.1 Cost-effective measures in the MPOWER package. Derived from WHO (2021).²⁹

Subject	Description
M	Monitoring tobacco use and prevention policies
P	Protecting people from tobacco smoke
O	Offering help to quit
W	Warnings about the dangers of tobacco
E	Enforcing bans on tobacco advertising, promotion and sponsorship
R	Raising taxes on tobacco

However, the gaps in the implementation of the FCTC articles remained and enlarged among all signatories.⁵ Chung-Hall et al. suggested the implementation of the FCTC measures was highest for smoke-free laws, health warnings and education campaigns, youth access law,²⁷ but measures for counter industry interference, regulate tobacco product contents, promote alternative livelihoods, and protect healthy environment remained the lowest.²⁷ Up to 2019, only Brazil and Turkey implemented all MPOWER demand-reduction strategies at their highest level.^{5, 31} According to Beaglehole et al. (2011), the full implementation of the WHO FCTC will have immediate benefits for health and economy.⁷ Between 2007-2014, 88 countries adopted at least one highest level MPOWER policy,³² which has resulted in a reduction in smoking prevalence of 7.26% and 22 million fewer projected smoking-attributable deaths.³⁰ Among countries with at least one highest level MPOWER policy, there were 19 high-income countries (HICs), 51 middle-income countries (MICs), and 18 low-income countries (LICs).³² Further between 2014-2016, there were 43 countries adopted at least one highest level

MPOWER policy.³³ As a party of the WHO FCTC since 2006, China failed to meet at least one highest level MPOWER policy until 2019.³⁴

1.2.2 Tobacco control in China

1.2.2.1 Administrative structure of the tobacco industry and the conflict of interests

The tobacco control system in China has a “top-level design”.³⁵ Enacted by the National People’s Congress (NPC), which is the highest legislative body of the state,³⁵ the Tobacco Monopoly Law (TML) was enacted in 1991 aiming at protecting tobacco industry and establishing it as a monopoly.¹⁰

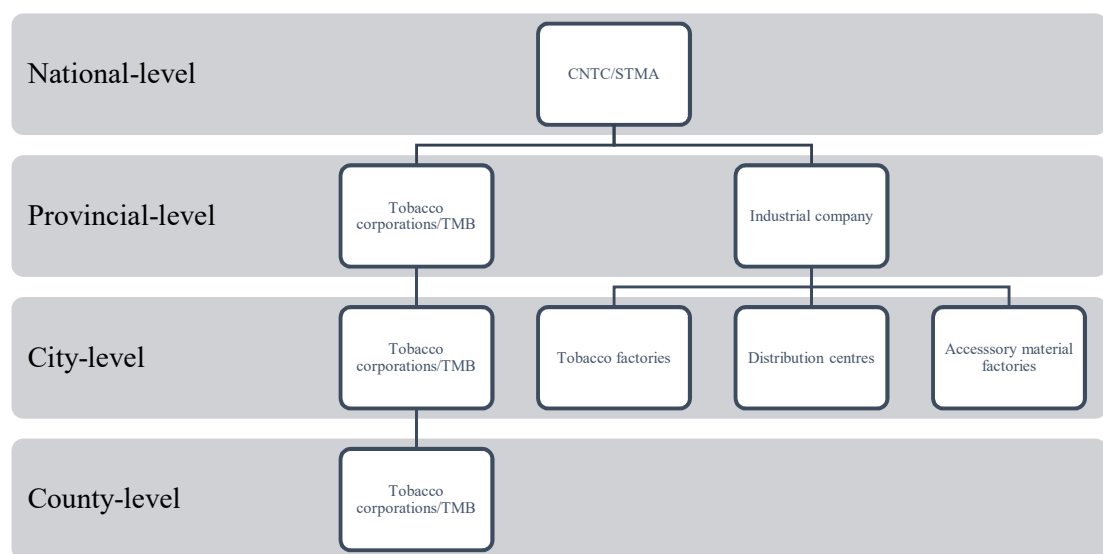


Figure 1.3 The parallel administrative structure of the tobacco industry in China. Adapted from Fang et al. 2016.³⁶

Representing the tobacco industry and acting in the capacity of the state tobacco monopoly,³⁷ China National Tobacco Corporation (CNTC) is a state-owned enterprise that covers the plantation of tobacco, the purchase and allocation of leaf tobacco, the manufacture and distribution of cigarettes, and other tobacco products, as well as the import and export of tobacco for the whole tobacco industry of China.³⁷ The State Tobacco Monopoly Administration (STMA) is part of the same organisation as the CNTC but works as a governmental body for the administration of the tobacco monopoly,^{37,38} which oversees and supervises the enforcement of the TML, as well as

relevant laws and regulations.¹⁰ In other words, the CNTC (i.e. the industry) and the STMA (i.e. the regulatory body) are the same entity that under the same management in practice.¹⁰ Indicating serious conflicts of interest,²² CNTC is the largest producer of cigarettes in the world, accounting for over 40% of production,^{10, 16, 39} while the STMA sets overall policies and delegates to CNTC full authority to implement these policies,^{10, 22} which have been identified as the most important barriers impeding the progress of radical tobacco control.^{22, 40}

Central planning is the major characteristic of the tobacco monopoly system of China.^{37, 41} The STMA/CNTC parallel management structure by levels (Figure 1.3),^{22, 36} under the jurisdiction of CNTC and STMA head office, has 33 provincial-level tobacco corporations/tobacco monopoly bureaus (TMBs),^{22, 37} 16 tobacco industrial enterprises, and many branches.²² The head office of STMA and CNTC is responsible for the centralising control of overall aspects of tobacco cultivation and cigarette manufacturing, whereas the provincial TMB have their own authorities in supervising the tobacco industry within their own region through multiple ways.^{16, 37}

1.2.2.2 Economic barriers to effective tobacco control

The economic barriers to effective tobacco control are daunting.¹⁰ Unlike its Western counterparts, China's tobacco industry still enjoys support from the government.¹⁰ It is encouraged by both central and provincial governments even though China has already become a signatory of FCTC.^{10, 16} As a state-owned enterprise and an economic pillar of China,⁴² the tobacco industry is maintained as a key stakeholder in the tobacco monopoly and tobacco control policymaking.^{37, 42} Tobacco has become the largest source of income for the Chinese government,^{16, 43} contributing to 9-12% of revenues,⁴⁴ and creating numerous job opportunities in factories (0.5 million), farms (3.6 million), and retail (4 million).³⁷ In 2009, tobacco companies sponsored about 79 welfare activities in 40 cities,⁴⁵ but the tobacco industry has no longer been allowed to sponsor public activities since 2015.¹⁴

Yang *et al.* (2015) indicated that the regional economies of provinces have also heavily relied on tobacco, which is a major source of tax revenue in many provinces,¹⁶ particularly in tobacco cultivation provinces such as Yunnan, Hunan, Guizhou, and

Sichuan.¹⁰ Due to the huge economic profits as well as the growing competition among tobacco manufacturers, provincial and other local governments have a vested interest in provincial-based protectionism policies to support the local tobacco industry.^{16, 46}

1.2.2.3 Implementation of WHO FCTC

The WHO Framework Convention on Tobacco Control (FCTC), which provides a framework to respond to global tobacco challenges, took effect in China in 2006.²² A series of national-level tobacco control policies recommended by the Articles of WHO FCTC and the MPOWER packages have been adopted since then.^{34, 47}

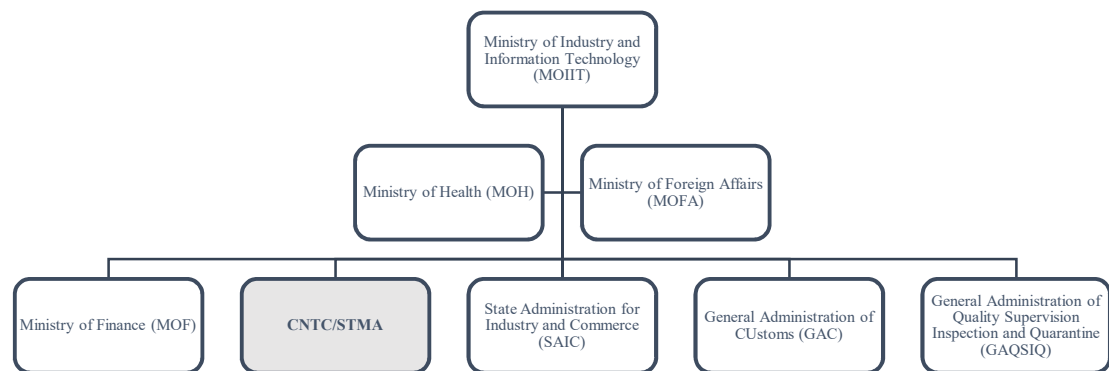


Figure 1.4 The organising institutions of the Inter-Ministry Implementation Coordination Mechanism (ICM) for WHO FCTC implementation in China. Reused with permission from Yang et al. 2015,²² License: 5355410344758.

Figure 1.4 presents the internal administrative structure regarding the implementation of WHO FCTC in China.²² The Inter-Ministry Implementation Coordination Mechanism (ICM) was established to coordinate the implementation of the FCTC within China in 2007.⁴⁸ The ICM is under the direct supervision of the Ministry of Industry and Information Technology (MOIIT), whereas the Ministry of Health (MOH) and the Ministry of Foreign Affairs (MOFA) act as associate group leaders.⁴⁸ As a government sector, STMA has also been placed as a stakeholder of the ICM, in charge of implementing the FCTC items regarding packaging, labelling, and regulations of the contents disclosures of tobacco products, which was a clear conflict of interest.²² Therefore, Yang et al. (2015) called for a further separation between tobacco control activities and the tobacco industry.²²

Continuous progress on the implementation of WHO FCTC has been made.²⁰ In the WHO report on the global tobacco epidemic 2019,³¹ no measures of MPOWER were assessed as the highest level (complete).^{20, 31} However, improvement was made in 2021 when two measures were assessed as the highest level in 2021 (Table 1.2).^{20, 34} Namely, (M) monitoring tobacco use and impact of prevention policies and (W) mass media policies were rated as “complete”, but more progress in (P) protect people from tobacco use is required to be made. By 2022, although more than 20 provincial-level administrative divisions or cities, including Beijing, Shanghai, etc., have enacted comprehensive smoke-free legislation,⁵⁰ Sun et al. (2022) suggest only local-level legislation is not sufficient to protect the majority of Chinese citizens.⁴⁹ In addition to calling for a stronger and more comprehensive nationwide smoke-free law,²⁰ Zhang et al. (2021) have also suggested the protection of youth from tobacco should be strengthened.²⁰ As has been legislated nationally in 2021, tobacco retail was not permitted to be allocated around school areas.⁵¹ However, because the prohibiting distance for tobacco retail is determined by local authorities, which vary greatly across regions, the established prohibiting distance for tobacco retail in certain regions may not be sufficient to protect youth from earlier smoking initiation.

Table 1.2 Assessment on achievement in implementing MPOWER measures in China, 2021. Adapted from WHO (2021)³⁴ and Sun et al. (2022).⁴⁹

Subject	Policies	Rating
Monitoring tobacco use and prevention policies	Recent, representative, and periodic data for both adults and youth	Complete
Protect people from tobacco use	Complete absence of ban or up to two public places completely smoke-free	No or weak
Offer help to quit tobacco use	Nicotine replacement therapy, and/or some cessation services (at least one of which is cost-covered)	Moderate
Warn about the danger of tobacco		
- Health warning policies	Medium size warnings with all appropriate characteristics or large warnings missing some appropriate characteristics	Minimal
- Mass media policies	National campaign conducted with at least seven appropriate characteristics including airing on television and/or radio	Complete
Enforce bans on tobacco advertising, promotion or sponsorship	Ban on national television, radio, and print media as well as on some but not all other forms of direct and/or indirect advertising	Moderate
Raise taxes on tobacco (54.5%)	≥50% and <75% of retail price is tax	Moderate
Note: Achievements in MPOWER measures are assessed as complete (highest), moderate, minimal, and no or weak policies (lowest). ^{31, 34}		

According to the Global Tobacco Epidemic 2021 report,³⁴ the implementation of MPOWER measures has contributed to the reduction in smoking prevalence from 30.5% (2008) to 23% (2021).^{20, 34} Initiated as a national strategy in 2016, *Healthy China 2030* aims to reduce smoking prevalence to 20% and reduce health inequalities.⁴⁷ Extra steps, such as place-based measures at the local level, may be required in addition to the continued enforcement of national-level measures contained in the WHO FCTC and MPOWER packages.

1.3 Policy Environment of Tobacco Retail

1.3.1 Global practice in tobacco retail licensing

Recommended by the WHO as an effective tobacco control strategy,^{52, 53} tobacco retail licensing has the potential to contribute to effective tobacco control by preventing smoking initiation and supporting smoking cessation.⁵³ In addition to tracking who is selling tobacco through a comprehensive registration system,^{53, 54} requiring a license for tobacco retail could discourage retailers from selling tobacco products,⁵⁵ improve compliance with retail regulations,^{54, 56} and strengthen other restrictions (e.g. reducing the number of tobacco retailers,^{53 55} denormalising tobacco use).⁵³

However, tobacco retail licensing systems are not common across the world and have often lacked political support, likely due to opposition by tobacco retailer organisations supported by the tobacco industry.⁵³ Even so, tobacco retail licensing has been proposed and implemented in some states of the US,⁵⁷ Canada,⁵⁸ Australia,⁵⁹ as well as a number of European countries, such as Finland, Hungary, France, Italy, Spain,⁵³ as well as Asian countries, such as Thailand⁶⁰ and China.

1.3.2 Tobacco retail licensing in China

In China, to sell tobacco products legally, all retailers are required to purchase tobacco retail licenses from Tobacco Monopoly Bureaus (TMB), the local branches of STMA. According to *Administrative Measures for Tobacco Monopoly Licenses*,⁶¹ to apply for a tobacco monopoly license for retail trade, the applicant shall meet the following conditions: 1) having funds which can meet the needs of engaging in the business of retail trade of monopoly products; 2) having fixed business premises that are independent from the applicants' domicile; 3) satisfying the requirements for the zoning regulations (i.e. spatial restrictions) of local tobacco retail; and 4) other conditions as prescribed by the STMA.

Tobacco retail licensing has a long history in China. However, the potential and public health benefits of tobacco retail licensing have not been fully developed in China, which may be because of the close involvement of the tobacco industry in the processing of tobacco control policymaking,²² as well as the ambiguous attitudes of

the central government of China towards the tobacco industry⁴⁹ due to the huge economic profits that come from the tobacco industry.

1.4 Geographical Approach to Smoking

A variety of important insights across a number of disciplines, such as medical and social sciences, have contributed to shaping public health policies/interventions regarding tobacco control by identifying the health impacts of tobacco smoking and second-hand smoking, social identity of smoking, stigmatisation of smoking, etc.⁶² Beyond individual-level health hazards of smoking (e.g. socioeconomic status, demographic characteristics, mental health status),¹⁸ following a multilevel structure, geographers and researchers from other disciplines have begun to make important contributions to knowledge and policymaking in recent decades by understanding how macro- (e.g. economy, urbanisation, population) and micro-level (e.g. local resources, social capital, tobacco retail densities within communities) geographical processes in relationship with smoking.^{18, 62}

Evidence documented in western high-income countries (HICs) suggests neighbourhoods may influence how people adopt and maintain health behaviours, such as smoking.⁶³ Higher smoking prevalence was found among the disadvantaged people and places,⁶⁴ indicating significant social and spatial inequalities in smoking.^{64, 65} Additionally, previous evidence has established that tobacco retail is disproportionately located in more socially disadvantaged neighbourhoods,⁶⁶⁻⁷¹ which in turn affects smoking behaviours through multiple pathways.⁶⁵ However, limited attention has been paid to research in the context of China, where the public health and economic burden of tobacco smoking is enormous, and the social order and structure may have changed dramatically under rapid urbanisation and a transition economy.

1.5 Problem Statement

1.5.1 Why Shanghai

Shanghai is the biggest and most populous megacity in China. Lower than the national smoking prevalence, the smoking prevalence in Shanghai is 19% for both sexes (2019).⁷² Shanghai has the most developed economy in China, and tobacco retailers are ubiquitous (Figure 1.5).



Figure 1.5 Tobacco retailers in Shanghai

China has experienced tremendous changes in urban landscapes, social order, and community structure under the transition economy and rapid urbanisation, particularly in megacities, which may influence tobacco smoking and the related health outcomes, further enlarging the health disparities.^{73, 74} Wu et al. (2005) suggested that lower-income households with smokers spend less on tobacco products.⁷⁵ Using a national representative sample from 1991-2004, Pan and Hu (2008) reported no significant impact of community economic development stage on the probability of smoking⁷⁶ and smoking frequency.⁷⁷ Although the socioeconomic structure in China differs from that in western HICs, recent studies in China may suggest western patterns in socio-spatial inequalities in tobacco retail and smoking might be anticipated in Chinese cities.⁷⁸ Neighbourhood-level characteristics, such as neighbourhood deprivation and social development, were found to be associated with smoking frequency.^{74, 79} These findings somewhat shared similarities with what has been documented in HICs. Exploring factors driving the socio-spatial inequalities in tobacco retail and smoking in Chinese megacities has become more critical, especially in Shanghai.

In addition to the potential transition in smoking pattern driven by the transition economy and rapid urbanisation in the context of Chinese megacity, Shanghai has enforced a range of tobacco control policies and regulations. Similar to what has been done in HICs, Shanghai enforced the first local-level smoke-free policies in 2009 at Expo.⁸⁰ Spatial restrictions for regulating tobacco retail, including prohibiting tobacco sales around school areas and setting district-level thresholds for the number of new tobacco retail licenses (abolished in 2018),⁸¹ which might not be commonly enacted in HICs, have been enacted and enforced in Shanghai.

Rapid urbanisation and the dramatic transition in community-level socioeconomic development, along with the enforcement of established tobacco-related policies, make Shanghai an important case to study the patterning of tobacco retail and the neighbourhood effects on smoking, which could provide useful insights for further development of comprehensive tobacco control strategies that could also be applied in other cities of China as well.

1.5.2 Conceptual framework

In order to enhance the understanding of how neighbourhood environments and policy environments mutually influence smoking in megacities of China using a case study of Shanghai. A proposed conceptual framework (Figure 1.6) is presented as a visual representation of how local policy environments and neighbourhood environments, including social and commercial environments, affect smoking behaviours among residents. The conceptual framework hypothesises that, in the context of Chinese megacities, local tobacco retail environments are shaped by local policy environments (i.e. place-based spatial restrictions) and neighbourhood social environments (i.e. deprivation and urbanity) mutually, which in turn affect smoking behaviours along with neighbourhood social environments with the adjustment for individual-level risk factors. The theories and the evidence that contribute to the proposed conceptual framework will be further demonstrated using a narrative review in the following chapter (Chapter 2).

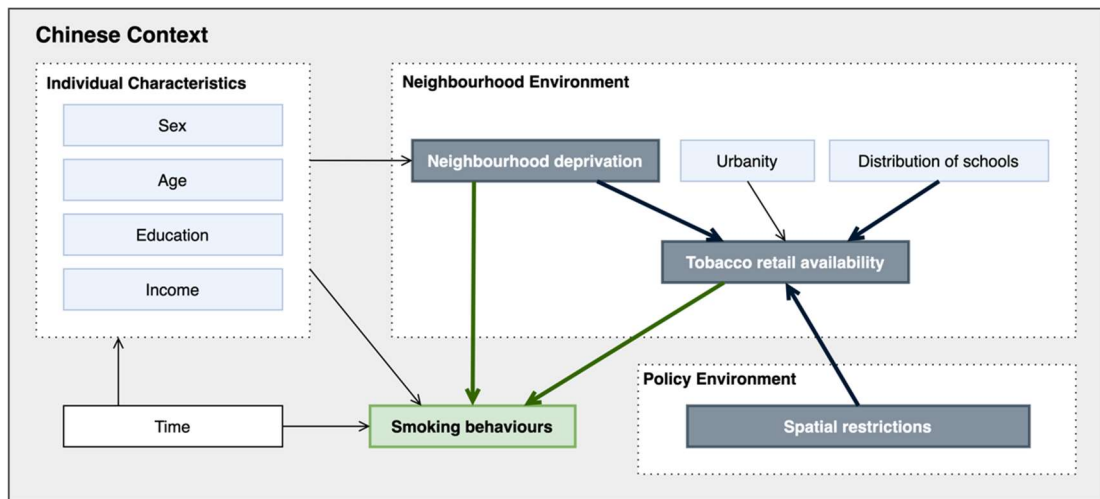


Figure 1.6 Conceptual framework on how local-level policy and neighbourhood environments affect individual-level smoking behaviours

1.6 Aims and Research Questions

This thesis aims to investigate the socio-spatial patterning of tobacco retail, the neighbourhood effects on smoking, and the plausible impacts of spatial restrictions aimed at reducing tobacco retail availability in megacities of China, using the case of Shanghai.

The following research questions will be addressed in this thesis, respectively:

- **Study 1 (Chapter 4).** Does the availability of tobacco retailing vary across different levels of neighbourhood deprivation and urbanity? Does this association vary by the type of tobacco retailer?
- **Study 2 (Chapter 5).** What is the retail distribution of tobacco retailers around public schools of Shanghai? Whether and to what extent do tobacco retailers cluster around public schools? To what extent have tobacco retailers complied with spatial restrictions for regulating tobacco retail that prohibit tobacco sales around school areas?
- **Study 3 (Chapter 6).** Are neighbourhood deprivation and tobacco retail availability associated with smoking behaviours? Do relationships between tobacco retail availability and smoking behaviours vary by levels of urbanity and neighbourhood deprivation?
- **Study 4 (Chapter 7).** What is the effectiveness of different spatial restrictions on tobacco retail availability reductions? Whether spatial restrictions aimed at reducing tobacco retail availability would increase the social inequality in tobacco retail availability?

1.7 Thesis Structure

This thesis comprises 8 chapters, including an introduction (Chapter 1), a literature review (Chapter 2), data and methods (Chapter 3), four empirical chapters (Chapters 4-7), and conclusions (Chapter 8).

The first chapter provides contextual information for the thesis, including (1) the burden of tobacco epidemics; (2) the progress in tobacco control; (3) the policy environment of tobacco retail; (4) geographical approaches to smoking; and (5) transitions in smoking patterns and the context of Shanghai, with a further description of the overall aims and the research questions of this thesis.

Chapter 2, the literature review chapter, reviews previous research about the relationship between tobacco retail availability, neighbourhood deprivation, and smoking; spatial restrictions for regulating tobacco retail; and their impacts in real-world practice and in simulation studies. Finally, this chapter identifies the knowledge gaps.

Chapter 3 introduces the data and the specific approaches used in this thesis for the following empirical chapters.

Chapter 4 is the first empirical chapter, which examines the socio-spatial patterning of tobacco retail availability and its association with neighbourhood deprivation using cross-sectional data in Shanghai, China.

Chapter 5, the second empirical chapter, examines the spatial patterning of tobacco retailers and the compliance of tobacco retailers around public school areas of Shanghai using a cross-sectional framework.

Chapter 6 examines the cross-sectional and longitudinal impacts of neighbourhood-level socio-commercial characteristics, including tobacco retail availability and neighbourhood deprivation, on individual-level smoking and smoking cessation.

Based on the findings from previous chapters (Chapters 4-6), Chapter 7 evaluates the effectiveness of stakeholder-informed spatial restrictions that are aimed at reducing tobacco retail availability as well as their equity impact in Shanghai.

The conclusion chapter, Chapter 8, synthesises key findings from four empirical chapters, indicating the strengths and limitations of the empirical chapters, making suggestions for future research, and emphasising the implications of the empirical chapters.

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Chapter 2 A narrative review on neighbourhood effects, tobacco retail availability, and smoking

2.1 Neighbourhood Effects on Smoking

2.1.1 Pathways of neighbourhood effects on smoking

2.1.1.1 Compositional or contextual effect

Evidence from high-income countries (HICs) has showed that people's health and health-related behaviours, such as smoking, are influenced by the residential area where they live.¹ There has been a long-standing debate over whether contextual effects or compositional effects have a major effect on health.² Compositional effects suggest that differences in health between places may result from differences in the kinds of people who live in these places, while contextual effects indicate that health disparities may be generated by differences in place.^{2,3} Policy interventions may only target improving individuals' circumstances if health disparities within areas can be entirely explained by individual-level characteristics of residents who reside in these areas, otherwise, policymakers should place emphasis on interventions targeting the "place" that residents reside in.² However, Macintyre et al. (2002) argued that, in reality, the distinction between composition and context may not be as conceptually clear as it appears.⁴ Individual or household characteristics might have been influenced by contextual features.⁴

2.1.1.2 Pathways linking place and smoking

Although individual-level attributes may result in differences in health-related behaviours and health outcomes among different subgroups of the population, the effects posed by place are also considerable.⁵ Driven by the opportunities of using socioecological data, the development of methodological techniques,^{4,5} and the acknowledgement of the importance of theoretical perspectives on place in affecting health, there is a growing interest in exploring how place affects individuals' health outcomes and how place-based policies can improve health outcomes.⁵ Therefore, it is argued that two key pathways, including place-based social practices and place-based policy regulations, have been established to link individuals, place, and smoking (Table 2.1).⁵

Table 2.1 Pathways of neighbourhood effects on smoking. After Pearce, Barnett and Moon (2012).⁵

Pathway	Hypothesis	Form
Place-based social “practices”	Social capital	Social support, social leverage, social participation, and informal social control
	Social practices	Social norms, smoking islands, denormalization, and interactions
	Contagion	Social networks
	Neighbourhood “disorder”	Psychological attributes (e.g. stress)
Place-based policy “regulations”	Smoking cessation policies	Smoke-free bans, cessation supports, etc.
	Tobacco retail availability	Access to tobacco retailers and related planning and zoning regulations, etc.
	Tobacco advertising	Billboards, advertising at points of sale, etc.
	Urban renewal	Urban regeneration, urban renewal, etc.

2.1.1.3 Place-based social “practices”

Place-based social “practices” refer to the act of smoking and regulatory measures in neighbourhoods that affect smoking, comprising four hypothesised pathways including social capital, social practices, contagion, and neighbourhood “disorder”.⁵

Various forms of social capital, such as social support, social leverage, social participation, and informal social control, have been linked to smoking in different ways.^{5,6} Social cohesion may encourage smoking,^{5,7-9} and smoking cessation^{10,11} across a range of contexts including England,⁷ Finland,⁸ and Sweden.⁹ Specifically, in England, all social support and social capital were found to be positively associated with smoking.⁷ Social participation was found to have positive effects on smoking cessation^{12,13} and smoking initiation.¹³ Using the British Household Panel Survey (BHPS) in 2003-2005, Giordano and Lindstrom (2011) suggested that remaining membership in local groups encouraged smoking cessation, while remaining a non-member of local groups was associated with increased risks of smoking initiation.¹³ Additionally, in the US, Ahern et al. (2009) found higher collective efficacy was associated with more smoking but was not statistically significant, whereas in neighbourhoods with smoking norms, collective efficacy was associated with higher-level smoking.¹⁴

Smoking behaviours could also be reinforced or weakened by the form of shared behavioural norms and cultures within neighbourhoods.⁵ Considered as rules regarding behaviour acceptance within a group, social norms are one important aspect

of neighbourhood social environment in relation to smoking cessation.¹⁵ Using qualitative methods, Stead et al. (2001) revealed that strong norms within communities with poor resources and high-level stress may encourage smoking and discourage smoking cessation.¹⁶ By examining a representative New York sample of data, Ahern et al. (2009) suggested that permissive smoking norms within neighbourhoods were positively associated with current smoking.¹⁴ Further, using the same dataset, Karasek et al. (2012) indicated that prohibitive norms of smoking within neighbourhoods were associated with higher rates of smoking cessation.¹⁵ Other forms, including “smoking islands” produced by the combination of smoking stigma and socio-spatial segregation,^{17,18} denormalization,¹⁹⁻²¹ and the interactions between smokers and non-smokers within neighbourhoods,¹⁷ have been suggested to contribute to the pathway that links place and smoking as well.⁵

The contagion pathway indicates smoking could spread through contact networks²²⁻²⁴ as a learned behaviour.⁵ For example, a Canadian study suggested an increased likelihood of smoking initiation among students with smoking friends and seniors (i.e. family members and senior students at school).²⁵

Furthermore, neighbourhood crime,²⁶⁻²⁸ physical disorder,^{29,30} and stress^{16,31-33} refer to the fourth place-based social “practices” pathway that sees smoking as a response to community stress.⁵ More evidence regarding the neighbourhood “disorder” pathway will be discussed in section 2.1.3.4.

2.1.1.4 Place-based policy “regulations”

Place-based policy “regulations” refer to a pathway that smoking behaviours could be influenced by shaping the constraints and opportunities in neighbourhoods through the assistance of policies and administrative decisions.⁵ Smoking cessation policies, such as smoke-free policies in public spaces, are related to a reduction in smoking prevalence³⁴⁻³⁷ and an increase in successful quitting attempts.^{36,38-42} In addition to reducing the exposure to second-hand smoke, banning smoking in certain types of places can denormalize smoking behaviour.^{5,43,44} However, it is controversial whether smoking cessation services could reduce smoking prevalence.⁴⁵⁻⁴⁷

Evidence from HICs has suggested tobacco retail, availability, and advertising within neighbourhoods could influence smoking behaviours through multiple pathways.⁵ Given this is a key theme in this thesis, a further demonstration of this pathway will be discussed in section 2.2.1.

The last place-based policy “regulation” pathway linking place and smoking is the urban renewal or urban regeneration programmes.⁵ As a place-based initiative, renewal or regeneration programmes aim to improve the personal conditions and living circumstances in deprived areas, which may affect individuals’ health outcomes and health-related behaviours like smoking.⁵ Bond et al. (2013) reported that individuals who experienced housing improvements in the most deprived neighbourhoods of Glasgow had a higher likelihood of smoking cessation.⁴⁸ Regeneration interventions may indirectly encourage smoking cessation because the ameliorated neighbourhood environment may encourage smoking cessation through environmental measures such as smoke-free policies, tobacco taxation, and social marketing.^{5,49} However, there is an argument about whether urban renewal or urban regeneration programmes will better serve the more deprived groups since the deprived groups might be displaced after neighbourhood environments are improved.^{5,50}

2.1.2 Individual characteristics in relation to smoking

A wide range of individual factors have been found to be associated with smoking behaviours. This section briefly reviews individual characteristics, including socioeconomic status (SES), demographic characteristics, and psychological/mental health status, in relation to smoking in recent decades.

2.1.2.1 SES and smoking

The association between individual SES and smoking/smoking cessation has been well established.⁵¹ Commonly measured by education, employment, and income, SES describes a person’s structural place in society.^{52,53} A social gradient in smoking has been documented in HICs.^{52,54} Overall, Hiscock et al. (2010)⁵² summarised that higher smoking prevalence was among those with lower SES,⁵⁵⁻⁵⁷ lower individual SES was

associated with increased levels of smoking,⁵⁸⁻⁶⁰ higher likelihoods of smoking initiation,⁶¹ and lower rates of smoking cessation.⁶²⁻⁶⁴

Different dimensions of SES may affect smoking independently. In most HICs, individuals with lower levels of education were associated with higher rates of smoking,^{52,56,61,63,65-69} high levels of tobacco consumption,⁷⁰ shorter-term of smoking abstinence,^{70,71} and lower likelihoods of smoking cessation.⁷⁰⁻⁷³

Unemployment was found to be associated with higher smoking rates^{46,65,66,68,69,74-76} and heavier smoking.^{77,78} Findings regarding the association between unemployment and smoking cessation were mixed. It has been suggested that higher cessation rates were among the employed,^{79,80} but Chen et al. (2001) did not find any significant association between employment and smoking cessation.⁸¹ Fagan et al. (2007) further suggested that longer durations of unemployment were found to be associated with a higher likelihood of quitting as opposed to those who had been employed for less than 6 months among the unemployed.⁶⁶

Compared with employment, the association between income and smoking was more complex and varied by context. Findings from the US and the UK suggested lower-income individuals were more likely to smoke^{68,82,83} and less likely to quit,^{71,84} with a lower smoking intensity.^{52,59} In Europe, however, the significant association between income and smoking among females was only found within those aged 25-34 years.⁸⁵ Another European study suggested adolescents from the highest quintile of income were more likely to become experimental smokers, weekly smokers, or daily smokers, and consume more cigarettes than adolescents from the lowest quintile of income.⁸⁶

Evidence regarding the socioeconomic gradient in smoking was also found in low and middle-income countries (LMICs).⁵² Higher odds of current smoking were associated with lower educational attainment, being employed, and lower-income.^{87,88} Using the Global Adult Tobacco Survey (GATS) and International Tobacco Control Survey (ITC), Nargis et al. (2019) found no clear evidence regarding the association between SES and smoking; that only the employed (pooled sample) was negatively associated with quitting in the last 12 months, while the association between education/income and smoking was non-significant.⁸⁹

2.1.2.2 Demographic characteristics and smoking

In addition to SES, smoking patterns vary with demographic features such as age,^{9,68,82,88} gender,^{9,68,90-92} marital status,^{9,12,82,87,91,93} race/ethnicity,^{68,82,93} etc, with significant geographical disparities.

The smoking pattern by age varies by context. In the US, using the National Health Interview Survey (NHIS), individuals aged 25-44 were found to have the highest prevalence of current smoking in 2000 (49.2%)⁶⁸ and 2018 (23.8%).⁸² In the UK, using a cohort (1972-2019) of England, Breton et al. (2021) found that the odds of current smoking peaked approximately at the age of 25.⁹⁴ However, the middle-aged group was found to be associated with higher odds of daily smoking in Sweden in 2004.⁹ According to the World Health Survey (WHS) conducted in 49 countries from 2002 to 2004, elderly females (age 55+) in low- and lower-middle-income countries (LLMICs) had a higher risk of current smoking, whereas elderly females (age 55+) in upper-middle- and high-income countries (UMICs) had a lower risk of current smoking.⁸⁸

Globally, a higher smoking prevalence was found among men.⁹⁵ Higher odds of being current smokers were also found among men in the US⁶⁸ and the UK.⁹⁰ However, in Sweden, the smoking prevalence among women (18.1%) was higher than among men (14.9%),⁹ while being men was associated with a higher likelihood of smoking cessation.⁹¹

Consistent evidence from HICs and LIMCs suggested marital status influences smoking. In the US, the current use of any tobacco product was higher among singles, never-married, living without any partner, divorced, separated, or widowed people.⁸² Further, Ramsey et al. (2019) suggested there was a lower smoking prevalence among the widowed than the divorced or separated.⁹³ The evidence from the UK suggested being married protected people from purchasing cigarettes, while separation increased the risk of smoking relapse and initiation.¹² In Sweden, unmarried or divorced individuals were more likely to become daily smokers⁹ and less likely to quit.⁹¹ A Danish study suggested divorced or widowed women smoked more than married women, while divorced, widowed, or never-married men smoked less compared with

married men.⁹⁶ The findings from LIMCs mostly agreed with the findings from HICs; divorced, separated, or widowed people were more likely to smoke than married or cohabiting people.⁸⁷

Most previous studies regarding race/ethnicity differences in smoking patterns were performed in the US.⁶⁸ In 2015, American Indian/Alaska natives (29.8%) and multiracial adults (27.4%) had higher tobacco use prevalence across the US.⁸² Being white and younger adults were associated with higher odds of current smoking.⁶⁸ Ramsey et al. (2019) discovered that smoking patterns differed by race/ethnicity and marital status, with cohabiters having the highest smoking prevalence among non-Hispanic Blacks, separated having the highest smoking prevalence among non-Hispanic Whites, and single/unmarried having the highest smoking prevalence among Hispanics.⁹³

2.1.2.3 Psychological factors and smoking

Consistent evidence has showed that poor mental health status is related to high smoking prevalence,⁹⁷⁻¹⁰⁰ higher likelihood of current smoking¹⁰¹⁻¹⁰⁴, heavy smoking,^{100,103,105,106} lower likelihood of smoking cessation,¹⁰⁶⁻¹⁰⁹ increased odds of relapse,^{107,108} and severe withdrawal symptoms when quitting.¹⁰⁶

In addition to the direct impact of poor mental health on smoking, mental health status could indirectly affect smoking by mediating the association between SES and smoking. Pisinger et al. (2010) found smokers with low SES were more likely to relapse during smoking cessation because of feeling nervous, restless, or depressed.¹⁰⁸ Another study conducted by Cambron et al. (2020) verified that individuals with lower SES experienced greater stress during a quit attempt.¹¹⁰

While mental health status could be served as a predictor of smoking, a number of studies have suggested that smoking could also be a causal risk factor for a range of psychiatric conditions and that stopping smoking can improve mental health.^{111,112} Some other evidence indicates smoking cessation is associated with reduced depression, anxiety, stress, and improved quality of life when compared with continuing smoking.¹¹¹ However, most studies on the role of individual-level

psychological factors in smoking have been conducted in HICs, with little evidence found in other contexts.

2.1.3 Neighbourhood characteristics in relation to smoking

As a wide range of individual-level risk factors for smoking have been discussed above, this section will concentrate on the established association between neighbourhood-level risk factors and smoking.

2.1.3.1 *Neighbourhood disadvantage and smoking*

Using a cross-sectional approach, evidence from HICs, including the US,^{27,113-117} the UK,^{118,119} Australia,^{120,121} New Zealand,^{122,123} France,^{124,125} and the Netherlands,^{32,126} has well documented that neighbourhood disadvantage is associated with higher rates of smoking initiation,¹¹⁶ higher rates of smoking,^{27,102,114,118-122,124-126} higher intensity of smoking,^{116,124,127} and lower rates of quitting.^{27,117,119,122}

Longitudinal studies have confirmed some of the findings from cross-sectional studies. Using data from two separate years, Karriker-Jaffe et al. (2015) suggested that neighbourhood disadvantage may increase smoking significantly in the US.¹¹⁵ Using longitudinal data, prior studies from the UK suggested that individuals living in neighbourhoods with greater area-level deprivation were more likely to smoke¹¹⁸ and less likely to quit.³¹ In Australia, neighbourhood disadvantage was found to be associated with lower chances of smoking cessation and a widening inequality in smoking in 2007 and 2009.¹²⁸ In Christchurch, New Zealand, individuals living in the least deprived neighbourhoods were more likely to quit than those from the most deprived, while the smoking rates among the most deprived neighbourhoods were 2.84 times higher.⁴⁵ In Finland, increased neighbourhood disadvantage was found to be associated with increased odds of being a current smoker and a heavy or moderate smoker.¹²⁹ More evidence on the impacts of neighbourhood disadvantage on smoking relapse is needed.

There is a lack of robust evidence regarding the association between neighbourhood disadvantage and smoking in LMICs. What is more, evidence from LMICs is the opposite of what has been found in high-income countries. Using cross-sectional data

in 2008, a non-linear relationship was found between neighbourhood deprivation and smoking prevalence in South Africa.¹³⁰ Through the examination of three waves of panel survey data, it was found that neighbourhood deprivation was associated with lower smoking intensity and a higher rate of quitting in Mexico.¹³¹

2.1.3.2 Racial/ethnic composition and smoking

Smoking disparities by neighbourhood racial/ethnic composition were mostly documented in western HICs. In the US, neighbourhoods with a lower percentage of black residents were a risk factor for cigarette use, and risk effects were greater in more disadvantaged neighbourhoods.¹³² Diez Roux et al. (2003) and Xue et al. (2007) revealed the neighbourhood effects were different for the blacks and the whites. Diez Roux et al. (2003) suggested young adults living in the most disadvantaged neighbourhoods were associated with greater odds of smoking among whites than among blacks.¹¹⁴ Xue et al. (2007) suggested black adolescents living in a neighbourhood with a higher proportion of black residents were associated with a lower risk of smoking, while white adolescents living in a neighbourhood with a high proportion of black residents were associated with an increased risk of smoking.¹³² Neighbourhood immigrant concentration, comprising the linguistic isolation, crowded housing, and proportion of Hispanics, was negatively associated with daily smoking.¹¹⁵ In New Zealand, Barnett et al. (2005) examined the smoking rates by deprivation among Māori and Pakeha, suggesting the impacts of relative deprivation on smoking were more important for Māori than for Pakeha in 1981 and 1996.¹³³ Hiscock et al. (2009) suggested that smoking rates were 2.33 times higher in neighbourhoods with the highest proportion of Māori.⁴⁵

2.1.3.3 Neighbourhood physical characteristics and smoking

A variety of neighbourhood physical characteristics have been identified to influence smoking. Contextual factors regarding physical disorder within neighbourhoods, such as litter and the absence of vegetation on facades, were strongly associated with a higher prevalence of smoking across European cities.²⁹ Physical quality, police attention, traffic noise, and population density within neighbourhoods have also been identified as contributing to individual-level smoking disparities in the Netherlands.³²

Perceptions of the provision of neighbourhood amenities and infrastructure seem to be strongly associated with individuals' smoking status in the UK and the US.^{30,134} The availability of greenspace within neighbourhoods was also found to be associated with smoking using the 2012 Health Survey of England (HSE) across 6,546 Lower Layer Super Output Areas (LSOAs).¹³⁵ Living in neighbourhoods with the highest greenspace quartile was associated with a lower smoking prevalence and a higher smoking cessation prevalence after controlling for a range of individual and area-level covariates, including SES.¹³⁵ However, the cross-sectional design of this study failed to reflect the causality.¹³⁵ Additionally, the measure of greenspace exposure did not account for population size within each LSOA. What is more, although this study controlled individual and area-level covariates, the pathway is not clear whether greenspace is directly associated with smoking or whether it is a moderator between the association between neighbourhood disadvantage and smoking.

2.1.3.4 Neighbourhood psychosocial characteristics and smoking

Neighbourhood psychosocial characteristics, such as more stressful living environments, could affect smoking.¹²¹ A qualitative study in Scotland suggested coping with stresses that were caused by material circumstances and the environment may encourage smoking and undermine smoking cessation.¹⁶ In the US, living in neighbourhoods characterised by a lower degree of trust and safety,¹³⁶ higher crime rates and perception of crimes,¹³⁷ and lower social cohesion¹³⁸ were associated with a higher likelihood of current smoking. A significant association between neighbourhood-level exposure to violence and ever-smoking among adolescents was also found in India.³³ Inconsistent findings from Rachele et al. (2016) suggested area-level perceptions of crime, safety, and social cohesion were not independently associated with smoking after controlling for neighbourhood disadvantage, while area-level perceptions of incivilities were associated with an increased likelihood of daily smoking.¹²¹ Similarly, Mayne et al. (2016) found that neighbourhood safety and aesthetic quality were associated with lower smoking prevalence, with a weaker or null association between neighbourhood social cohesion and smoking.¹³⁹

Psychological factors, such as poor mental health conditions, may serve as an important mediator of the association between neighbourhood inequalities and

smoking.^{52,62,115} Previous studies indicated that smokers with lower SES were more likely to be exposed to stressful living environments within neighbourhoods,^{62,140} which encouraged daily smoking¹⁴¹ and discouraged smoking cessation.^{52,62,142,143} However, a more recent study suggested that perceived social pressure and support quit were not found to be associated with daily smoking among socioeconomically disadvantaged smokers.¹⁴⁴

2.1.4 Evidence from China

So far evidence regarding how individual and neighbourhood-level factors affect smoking in HICs has been discussed, this section will focus on the established evidence from China.

2.1.4.1 Individual characteristics and smoking

In the Chinese context, previous research has examined the relationship between individual characteristics and smoking, but findings on them were inconsistent.

Among individuals aged 60 years and over (n = 6071) across 5 provinces of China in 2007-2009, 45.6% and 20.5% of men were current smokers and former smokers, while it was 11.1% and 4.5% of women, respectively.¹⁴⁵ Furthermore, current smoking was negatively associated with increased age for both sexes but positive with age for men.¹⁴⁵ Another study using national representative adult samples (n = 21,138) found no significant association between age and smoking prevalence.¹⁴⁶

Among adults in tobacco-cultivating rural areas of China, individual characteristics including being male, younger, and having a lower education level were found to be associated with current smoking.¹⁴⁷ Further to the significant age and gender differences in smoking behaviours, Zhang et al. (2013) suggested current smoking was found to be associated with low SES, alcohol drinking, being never-married, and poor mental health conditions,¹⁴⁵ while smoking cessation was associated with having a secondary school education and above, having a middle-high income, being a businessman, and being widowed.¹⁴⁵

Previous findings regarding the association between income and smoking differed by age group. Yang et al. (2015) found gender, occupation, and income were associated with smoking prevalence among individuals aged 15 years and older.¹⁴⁶ However, with a focus on individuals aged 45 years and over, the association between income and smoking was non-significant.¹⁴⁸

2.1.4.2 Neighbourhood-level characteristics and smoking

It may be because of the availability of data that research about neighbourhood/area-level effects on smoking in China is scarce. Table 2.2 summarises the key findings regarding the area/neighbourhood-level risk factors of smoking.

Using the China Health and Nutrition Survey (CHNS) from 1991 to 2004, Pan and Hu investigated the association between a variety of neighbourhood contextual variables in relation to current smoking and smoking frequency.^{149,150} Overall, over time, current smoking was found to be negatively associated with community size and positively associated with free market local cigarette prices, while community size and average community daily wage were negatively associated with smoking frequency.¹⁴⁹ Further examining the association by each wave, community size was positively associated with current smoking in 1991, the average daily wage of workers in a community and free market cigarette prices were negatively associated with smoking frequency in 1991 and in 1993, while community size was negatively associated with smoking frequency in 2000.¹⁵⁰

The area-level contextual impacts on smoking showed geographical differences. Pan et al. (2020) found a greater reduction rate in smoking initiation across birth cohorts among urban residents than rural residents in 2006-2015 using a national representative sample.¹⁵¹ Liu et al. (2022) suggested smoking inequality by SES showed regional disparities in China with higher-level smoking inequality by SES among females in the northeast.¹⁵² Examining the township-level contextual impact on smoking in tobacco-cultivating rural areas of China, Cai et al. (2012) suggested that living in towns with higher income was associated with lower odds of current smoking.¹⁴⁷

A small number of studies in the Chinese context investigated the effects of neighbourhood social environments on smoking behaviours. In Shanghai, adolescents who felt unsafe were nearly twice as likely to have ever smoked compared with those who felt safe in their neighbourhoods, and they were less likely to have ever smoked if they perceived their neighbourhoods as more socially cohesive.³³ Although this finding agreed with what has been documented in HICs, the cross-sectional design and the small sample size ($n = 438$) reduced the quality of this evidence. More recently, using cross-sectional survey data across 288 communities in 2015, Chen et al. found that a higher level of neighbourhood deprivation is associated with a severer intensity of smoking, which also moderates the association between perceived stress and smoking intensity.¹⁵³ Compared with those living in the least deprived neighbourhoods with same-level stress, males living in the most deprived communities with moderate-level stress were associated with fewer cigarettes, whereas females living in the most deprived communities with high-level stress were associated with more cigarettes.¹⁵³ Using longitudinal data (1991–2011) that includes 235 communities in China, Yang et al. (2017) indicated that community-level social development is negatively associated with smoking frequency.¹⁵⁴ Furthermore, higher-income individuals living in communities with higher levels of social development were found with decreased frequencies of smoking but with increased frequencies of smoking in communities with lower levels of social development.¹⁵⁴ However, both of these two established studies focused on the neighbourhood effects of smoking intensity; there is a lack of evidence on the impact of neighbourhood social environments on smoking. In addition, the contextual impact on smoking cessation has seldom been investigated in the Chinese context. Considering the geographical difference in the area/neighbourhood effects on smoking behaviours, for developing effective tobacco control initiatives, it is critical to provide more local-level evidence.

Table 2.2 A summary of previous important evidence from China

Study	Outcome	Study population	Area	Area Characteristics	Individual characteristics	Design	Significance
Pan & Hu (2008) ¹⁴⁹	Smoking frequency & smoking prevalence	Participants aged 15 years and over from the China Health and Nutrition Survey (CHNS) in 1991-2004 (n = 3,222)	Residential community	Proxy community economic development stage, local free market cigarette price, community size in thousands of households, average daily wage of workers in a community	Age, sex, education, physical activity, urban residence, employment, secondary occupation, Working for state-owned or collective enterprise, no. of smokers in households, household size, time	Longitudinal	Community size and free-market local cigarette prices were associated with current smoking. Interacting with time, the free-market local cigarette price was associated with a decreased probability of smoking. Community size and average community daily wage were negatively associated with smoking frequency.
Pan & Hu (2008) ¹⁵⁰	Smoking frequency & smoking prevalence	9,447 individuals aged 15 years or older in 1991, 8,882 individuals aged 15 years or older in 1993, 11,241 individuals aged 15 years or older in 1997, 10,206 individuals aged 15 years or older in 2000, and 10,330 individuals aged 15 years or older in 2004.	Residential community	Proxy community economic development stage, local free market cigarette price, community size in thousands of households, average daily wage of workers in a community	Age, sex, education, physical activity, urban residence, employment, secondary occupation, Working for state-owned or collective enterprise, no. of smokers in households, household size, time	Longitudinal	Community size in thousands of households was positively associated with current smoking in 1991. In 1991 and 1993, the average daily wage of workers in a community and free market cigarette prices were negatively associated with smoking frequency. In 2000, community size was negatively associated with smoking frequency.
Cai et al. (2012) ¹⁴⁷	Current smoking versus non-current smoking	Participants aged 19 years and over in Tonghai county of Yunnan Province (n = 279,404)	Township	Percentage with primary education or higher, percentage of ethnic minorities, average yearly income, population size, area of township, area of tobacco cultivation	Age, sex, ethnicity, yearly household income, education and tobacco-cultivating status	Cross-sectional	Average yearly income was negatively associated with current smoking.

Mmari et al. (2014) ³³	Never smoking versus ever smoking	Participants aged 15-19 years in Shanghai, China in 2013 (n = 438)	Residential community	Neighbourhood problems including social cohesion, perceived safety, community violence	Age, gender, perceived economic status, in-school status, and housing stability	Cross-sectional	Perceived safety was positively associated with ever smoking, while neighbourhood social cohesion is positively associated with smoking cessation.
Yang (2017) ¹⁵⁴	Smoking frequency	Participants aged 18 years and over from the CHNS from 235 communities across China in 1989-2011 (n = 12,432)	Residential community	Neighbourhood economic development, neighbourhood social development, income inequality, residential turnover, ethnic heterogeneity, population, urban/rural	Age, birth cohort, income, education, sex, ethnicity, occupation class	Longitudinal	Community-level social development is negatively associated with smoking frequency with the adjustment of other individual and community-level covariates.
Pan et al. (2020) ¹⁵¹	Smoking initiation	Participants aged 18 years and over from the CHNS who were enrolled in 2006–2015 and born between 1950 and 1997 reported smoking initiation between 10 and 24 years of age (n = 10,032).	Residential community	Urbanisation	Sex, education	Longitudinal	There was a reduction in smoking initiation rates across the birth cohorts for both urban and rural participants, but the reduction was more significant among urban participants.
Chen & Kim (2021) ¹⁵³	Smoking frequency	10,815 individuals aged 21 years and over from 288 communities across China in 2015 (CHNS)	Residential community	Neighbourhood deprivation	Perceived stress, age, marital status, education, employment status,	Cross-sectional	Community deprivation was positively associated with smoking intensity after controlling for individual covariates for both sexes. Deprivation significantly moderated the association between perceived stress and smoking intensity.

Liu et al. (2022) ¹⁵²	Smoking inequality by SES	17,708 individuals aged 45 years or older across 28 provinces of China (2011-2018).	Region	Neighbourhood deprivation	Education, occupation, household characteristics and durable consumer goods.	Longitudinal	Females in the northeast region of China had higher levels of smoking inequality by SES than females in other regions. Within the northeast region of China, smoking inequality by SES increased for both sexes (age < 60 years), but the increase was more considerable among males between 2011 and 2018.
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2.2 Tobacco Retail and Smoking

2.2.1 Pathways linking tobacco retail and smoking

As mentioned in 2.1.1.4, place-based “regulations” constraining tobacco availability and environmental opportunities for tobacco products within neighbourhoods could shape the smoking behaviours of local residents.⁵ According to Pearce et al. (2011), better access to tobacco retailers, such as higher density or better proximities in neighbourhoods, potentially promotes smoking by providing individuals with easier access to obtaining tobacco products,^{5,155} simulating and encouraging tobacco consumption through price reductions resulting from intensifying competition among local tobacco retailers.⁵ Along with the display of tobacco products and the tobacco advertising at the point of sales, tobacco retail may undermine smoking cessation by prompting impulse purchase^{156,157} and environmental cues on smoking,^{5,158} normalising and increasing public acceptability of smoking.^{159,160} Similar pathways have also been summarised by Cantrell et al. (2015).¹⁶¹

2.2.2 Socio-spatial differences in tobacco retail availability

2.2.2.1 *Within residential neighbourhoods*

In this review of Valiente et al. (2021) defined tobacco retail availability as the supply of tobacco retailers by considering the count of tobacco retailers, the population size, and the types of tobacco products that could be obtained from these retailers within a given area.¹⁶² Generally, evidence from HICS indicated that tobacco retailers are more likely to concentrate in socially and economically disadvantaged,^{127,159,163-171} more urbanised,^{159,163,164,170} and high-minority neighbourhoods.^{163,164,170}

In the US, Schneider et al. (2005) found areas with lower income and higher proportions of African-Americans and Latinos had better access to tobacco products.¹⁶⁵ Siahpush et al. (2010) also confirmed that the mean household income of neighbourhoods was negatively associated with the percentage and the number of stores that sold tobacco.¹⁶⁷ An exception was found by Peterson et al. (2005) in Iowa, where counties with higher densities of tobacco retailers were also associated with higher median household income.¹⁷² Data from Chicago suggested lower densities of

tobacco retailers were found within areas with higher proportions of African-Americans and white residents, but not in areas with higher proportions of Hispanic and foreign-born residents.¹⁶⁶ Novak et al. (2006) also suggested that residential mobility and poverty were negatively associated with higher densities of tobacco retailers.¹⁶⁶ In addition to the greater availability of tobacco retailers in neighbourhoods with large proportions of African-Americans and Hispanics, through a nationwide assessment, Rodriguez et al. (2013) suggested more urbanised neighbourhoods were found with greater densities of tobacco retailers, with a significant urban-rural disparity in tobacco retail availability by all neighbourhood sociodemographic categories except for poverty.¹⁷⁰ In contrast to previous findings, Vyas et al. (2020) did not find an association between the concentration of tobacco retailers and neighbourhood income or ethnic composition using data from San Francisco, US, but they identified the types of land use as a predictor of the unequal concentration of tobacco retailers.¹⁷³ Even though these studies were all conducted within the settings of the US, slightly geographical differences existed. In other contexts, through examining a national sample in Scotland, Shortt et al. (2015) uncovered the social gradient in neighbourhood-level tobacco retail availability, as well as the greater availability of tobacco retailers in more urbanised areas.¹⁵⁹

2.2.2.2 Within child spaces

Compared with the established studies focusing on the tobacco retail environment within neighbourhoods, the evidence on the retail environment of tobacco within child spaces such as school is limited. The tobacco retail exposure to the underage also differed by area-level socioeconomic characteristics. In New South Wales, Australia, higher median densities of tobacco retailers were found around schools than the state median.¹⁷⁴ For tobacco retailers within 500-100 m of school, the number of schools was positively associated with deprivation.¹⁷⁴ Using Global Positioning System (GPS) tracking data, Caryl et al. (2019) examined the tobacco retail exposure to children aged 10-11 years in Scotland suggesting children from the most deprived areas were exposed to much greater level of tobacco retail, with most exposure from convenience store.¹⁷⁵ Compared to the conventional approach (i.e. count of tobacco retailers or count of tobacco retailers per capita) to calculate stationary tobacco retail availability

that is constrained within given geographical areas (e.g. administrative boundaries), the GPS measure has a major advantage in capturing the dynamics of real retail exposure.^{162,175}

2.2.3 Tobacco retail availability and smoking

Previous studies, mostly from HICs, have found that higher tobacco retail availability is associated with higher smoking prevalence,^{158,166,176,177} earlier smoking initiation,¹⁷⁸ higher susceptibility to smoking,^{169,123 179} greater tobacco consumption,¹²⁷ and lower rates of smoking cessation.¹⁸⁰

2.2.3.1 Tobacco retail availability and smoking among adults

The association between tobacco retail availability and smoking was largely dependent on cross-sectional studies. There is a positive association between availability and smoking prevalence among adults. In Iowa, the US, Reid et al. (2005) found the relationship between tobacco outlet density and smoking prevalence was greater among counties with a higher percentage of African-Americans.¹⁷⁶ Shareck et al. (2016) reported that youths who live in neighbourhoods with high and medium numbers of tobacco retailers within the activity space were more likely to smoke.¹⁷⁷

In the US, the concentration of convenience stores was found to be associated with smoking intensity that people living in high SES neighbourhoods with a high density of tobacco retailers smoked more cigarettes.¹²⁷ Cantrell et al. (2016) reported that individuals aged 25-34 living in neighbourhoods with higher densities of tobacco retailers had greater odds of cigarette smoking initiation, while greater odds of non-cigarette combustible initiation were among those aged 18-24 years.¹⁷⁸ Using drive-time to the nearest supermarket and convenience store along a road network, in New Zealand, individuals living in neighbourhoods with the best access to supermarkets and convenience stores were found to be more likely to become current smokers.¹²³ Another study from New Zealand had a similar finding that neighbourhood-level mean tobacco retail density was positively associated with current smoking.¹⁷⁴ In Scotland, individuals who lived in areas with the highest densities of tobacco retailers were more

likely to become current smokers when compared to residents of areas with the lowest densities.¹⁷⁹

2.2.3.2 Tobacco retail availability and smoking cessation among adults

A number of studies have examined the cross-sectional impacts of tobacco retail availability on smoking cessation. In the US, the density of tobacco retailers within 500 metres of the home residence was found to be negatively associated with quitting.¹⁶¹ Shareck et al. (2020) suggested further distances to tobacco retailers in the activity space are associated with increased smoking cessation among young adults.¹⁸¹ In Scotland, people in areas with greater densities of tobacco retailers are less likely to quit.¹⁷⁹

Although most previous research is based on a cross-sectional approach, here is some more robust evidence based on longitudinal data. Reitzel et al. (2011) examined impact of densities and proximities of tobacco retailers on smoking cessation independently and discovered that increased proximities (< 200 m and < 500 m) to the closest tobacco retailers were associated with the lower likelihood of smoking abstinence, but the impact did not vary across postquit weeks.¹⁸² Halonen et al. (2014) and Pulakka et al. (2016) both suggested there were negative associations between proximities to tobacco retailers and smoking cessation in Finland. An increase in distance from home to the nearest tobacco outlet may increase the rate of quitting among smokers¹⁸³ whereas living within walking distance (< 500 m) of tobacco store reduced the likelihood of smoking cessation for male moderate/heavy smokers.¹²⁹ In Canada, through examining the panel data from the Ontario Tobacco Survey of smokers in 2005-2008, Chaiton et al. (2016) found the increased density of tobacco retailers was associated with decreased quitting attempts in higher-income neighbourhoods, and the existence of a tobacco retailer within walking distance from home was associated with reduced odds of making quitting attempts.¹⁸⁴ In an English setting, Han et al. (2014) examined the impacts of proximity to tobacco retailers on smoking cessation over time.¹⁸⁵ However, the association between proximity to a tobacco retailer was not found to be associated with sustained smoking abstinence.¹⁸⁵ Using a national representative adult smokers' sample from the international tobacco control (ITC) Canada survey, Fleischer et al. (2019) suggested that the densities and the proximities to tobacco

retailers were not associated with smoking cessation and relapse.¹⁸⁶ Different availability measurements^{162,187} and study settings may result in inconsistent findings regarding the association between tobacco retail availability and smoking cessation.

Using meta-analysis, Lee et al. (2021) systematically reviewed 37 studies regarding the associations of tobacco retail density and proximity with smoking behaviours among adults systematically, suggesting larger effect sizes from longitudinal studies.¹⁸⁷ Lee et al. (2021) also reported the smaller effect sizes in research examining the impacts of tobacco retail availability on relapse, calling for more studies focused on relapse directly.¹⁸⁷

2.2.3.3 Tobacco retail availability and smoking among students

Typically, evidence from the HICs indicated that smoking initiation occurs during the high school years (14-17 years).¹⁸⁸ Reducing demand and perceived availability of tobacco is perhaps the most important predictor of smoking initiation among students.¹⁸⁹ The association between tobacco retail availability and smoking among students has been examined in the US,^{158,190,191} Canada,¹⁹² Australia¹⁹³ New Zealand¹⁹⁴ and UK.¹⁸⁰

In the US, Novak et al. (2006) found that retail density was significantly associated with smoking prevalence among youth (ages 11-23) that living in areas with the highest densities of tobacco retailers were more likely to have smoked in the past month compared with those who lived in areas with the lowest densities of tobacco outlets in the US.¹⁶⁶ Henriksen et al. (2008) reported that current smoking prevalence was higher at schools in neighbourhoods with the highest densities of tobacco retailers, while neither the presence of tobacco retailers within 1000 ft of a high school nor the proximity of tobacco retailers to a school were found to be associated with smoking prevalence.¹⁵⁸ Using different density measures, Pokorny et al. (2003) and McCarthy et al. (2009) suggested there was a positive association between availability and smoking initiation among students.^{191,195} The number of retailers who illegally sold tobacco per 1,000 adolescents in the community was significantly associated with smoking initiation among students in Grades 7-8 after controlling for individual risk factors, but not continued cigarette use,¹⁹⁵ while the greater number of tobacco

retailers within 1 mile of schools was associated with a higher likelihood of experimental smoking among high and middle school students.¹⁹¹ Compared with proximities to tobacco retailers, it seems like densities of tobacco retailers were more strongly associated with tobacco use among students in the setting of the US.

Findings from other HICs were not consistently in line with what has been documented in the US. In Ontario, Canada, greater numbers of tobacco retailers around schools were found to be associated with greater odds of purchasing their own cigarettes¹⁹⁰ and a higher likelihood of being a never smoker turning into a future smoker among students in Grades 9-12.¹⁹² In Australia, Scully et al. (2013) found a positive association between the density of tobacco retailers and cigarette consumption among adolescent smokers in Australia but not for smoking prevalence.¹⁹³ In New Zealand, current smokers among youths were more likely to purchase tobacco if the density of tobacco retailers around their schools was high.¹⁹⁴ In Scotland, Shortt et al. (2016) revealed that the density of tobacco retailers within residential neighbourhoods was found to be associated with increased odds of experimental smoking and current smoking among adolescents after controlling for all confounders, but those attending schools with the highest densities of tobacco retailers had lower odds of experimental smoking.¹⁸⁰ As summarised in the review by Marsh et al. (2019), smoking among youth was associated with the density of tobacco retailers rather than the proximity.¹⁹⁶

2.2.4 Evidence from China

2.2.4.1 Tobacco retail environment within neighbourhoods and around schools

The evidence regarding the socio-spatial patterning of tobacco retail and its impact on smoking is scarce in the Chinese context. Gong et al. (2010) and Wang et al. (2017) examined the density of tobacco retailers within neighbourhoods in Hangzhou¹⁹⁷ and Changsha,¹⁹⁸ respectively. The average density of tobacco retailers in Hangzhou is 12.2 retailers per neighbourhood and 2.4 retailers per 1000 residents,¹⁹⁷ while the average density of tobacco retailers within neighbourhoods was 99.7/km² in Changsha.¹⁹⁸ However, due to the inconsistency in density measures, the findings from these two studies cannot be compared.

A limited number of studies have examined the tobacco retail environment around schools in different cities across China. In Beijing (2008), an average of two tobacco retailers were in the vicinity of a school.¹⁹⁹ Gong et al. (2010) and Wang et al. (2017) also examined the tobacco retail patterning around schools in Hangzhou and Changsha. In Hangzhou, 46.7% and 80% of schools had at least one tobacco retailer within 50 m and 100 m distances, respectively, with no significant disparities between the number of tobacco retailers within 100 m and outside of 100 m of schools.¹⁹⁷ An average of three tobacco retailers was found in the vicinity of tobacco retailers within 100 m of a school in Changsha, with 98% of schools having at least one tobacco retailer around, which further increased to 6.7 tobacco retailers as the distance increased to 101-200 m.¹⁹⁸ More recently, Nian et al. (2022) investigated tobacco retail distribution around schools in 10 cities across China by randomly sampling 1512 tobacco retailers around 904 schools, suggesting that 57% of urban schools and 71% of rural schools had at least one tobacco retailer within 100 m (urban setting) and 250 m (rural setting) distance of schools.²⁰⁰ The distribution of tobacco retailers (n = 141) around schools (n = 128) was also investigated in Shanghai in this research, suggesting that 53.1% of schools had one tobacco retailer within 100 m of a school.²⁰⁰

All established studies regarding tobacco retail environment within neighbourhoods and around schools used audit sampling approach. By only sampling a fraction of tobacco retailers, a total of 1,639 tobacco retailers from 3 more urbanised districts were sampled by Gong et al. (2010),¹⁹⁷ which may result in bias due to the loss of tobacco retailer data, particularly in less urbanised areas. Similarly, 739 tobacco retailers within 200 m of the front entrance of 308 selected schools were sampled in Changsha.¹⁹⁸ Although Nian et al. (2022) investigated the tobacco retail environment around schools in 10 Chinese cities, as the largest megacity of China that is experiencing rapid urbanisation, only 128 schools and 141 tobacco retailers in Shanghai were audited.²⁰⁰ Although these studies could give an overall image of the tobacco retail environment around schools in Chinese cities, due to the potential bias resulting from strategies of audit sampling and significant geographical differences across China, prior studies might not provide robust evidence for effective tobacco control policymaking at the local level.

2.2.4.2 Socio-spatial patterning of tobacco retail

Two other Chinese studies examined the socio-spatial differences in tobacco retail. Using a randomly sampling approach, Wang et al. (2015) examined the availability of 739 tobacco retailers in 36 neighbourhoods of Changsha using the number of tobacco retailers per neighbourhood and the number of tobacco retailers divided by the area of the neighbourhood that the retailer was allocated.²⁰¹ All sampled neighbourhoods were grouped into 3 levels by neighbourhood-level average property price (Low: < 5000 CNY; Median: 5000-8000 CNY; High: > 8000 CNY). Neighbourhoods with median level average property prices were found to have greater numbers of tobacco retailers per neighbourhood ($n = 12.7$) and greater numbers of tobacco retailers per km^2 ($n = 101.4$). However, neither of these availability measures differed statistically by levels of neighbourhood average property prices ($p = 0.6796$).²⁰¹ Wang et al. (2016) explored the spatio-temporal patterning of illicit tobacco retailers in Changsha, suggesting there was a clustering pattern of illicit tobacco retailers.²⁰² In addition to identifying population density as an important driver of the patterning of illicit tobacco retailers, other factors including the number of kindergartens and nurseries, the proximity to the borders, and the number of students of primary and middle schools were also associated with the ratio of the number of events involving illicit tobacco trade to the total population within 22 administrative units in 2011-2012.²⁰²

2.2.4.3 Provincial-level contexts and smoking

Notably, established Chinese studies regarding the neighbourhood-level tobacco retail environment have not been linked to smoking behaviours. But there were two studies that examined the association between provincial-level context and smoking behaviours.

Yang et al. (2015) suggested individuals living in provinces with higher-level cigarette production were more likely to be current smokers,¹⁴⁶ while Hoe et al. (2021) revealed that provincial-level per capita cigarette production, per GDP cigarette production, and city-level tobacco retail density were significantly associated with second-hand smoke exposure.²⁰³ A plausible explanation could be that greater cigarette production led to greater competitiveness in the local retail market and lower prices, which further

resulted in higher consumption.¹⁴⁶ Additionally, smoking could be a kind of more acceptable behaviour in tobacco-cultivated provinces. Although these two studies established the relationship between the tobacco retail environment and smoking/second-hand smoking, both of them were performed at a higher administrative level, whereas neighbourhood-level evidence remains absent.

2.3 Regulating tobacco retail and smoking

2.3.1 Spatial restrictions for regulating tobacco retail

Given the evidence regarding the pathways linking tobacco retail and smoking, regulating tobacco supply has been considered a new opportunity for effective tobacco control.^{204,205} According to Glasser and Roberts. (2020),²⁰⁶ there are four major types of spatial restrictions that have been widely used for regulating tobacco retail in Western HICs (Table 2.3).

These place-based spatial restrictions have been enforced under different thresholds in cities across the US, the UK, Canada, Australia, and some European countries (Table 2.4).²⁰⁶ Previous research from HICs suggests these spatial restrictions have the potential to reduce tobacco retail availability substantially,²⁰⁷⁻²¹⁴ whereas the effectiveness of different spatial restrictions varies by type and geographical context.²¹³

Table 2.3 Major types of spatial restrictions for regulating tobacco retail. Adapted from Glasser and Roberts (2020).²⁰⁶

Type	Description
Capping	Capping the number of tobacco retailers in an given geographical area
Ban of sales	Ban of tobacco sales in specific type of tobacco retailers
School buffer exclusion zone	Prohibiting tobacco retail around schools within given distances
Minimum spacing	Requiring a minimum distance between two neighbouring tobacco retailers

Table 2.4 Spatial restrictions aimed at reducing tobacco retail availability in HICs

Country	Capping	Ban of Sales	School Buffer	Minimum spacing
US ^{171,206-209,212,215,216}	•	•	•	•
UK ²¹⁶		•		
Canada ²¹⁶		•		
France ^{206,216}		•		
Italy ^{206,217}		•		•
Spain ^{217,218}				•
Hungary ^{216,219}	•	•		

2.3.2 The effectiveness of spatial restrictions

Most studies examining the effectiveness of spatial restrictions in reducing tobacco retail availability were performed in the US, including San Francisco,^{206,209,215,216} Santa Clara County,²¹² Philadelphia,^{206,207} New York City,²⁰⁸ North Carolina,^{171,210} and

Missouri.²²⁰ Another study examined the compliance of tobacco retailers with spatial restrictions in Madrid, Spain. Table 2.5 summarises the effectiveness of spatial restrictions (enforced and simulated) in reducing availability of tobacco retailers. Overall, all spatial restrictions showed considerable capabilities in reducing availability. Myers et al. (2015) tested the considerable capabilities of “ban of sales”, “school buffer exclusion zone”, and “minimum spacing” in reducing availability using real data in 2012, with the greatest impact found for minimum spacing in North Carolina, the US.²¹⁰ According to Glasser and Roberts (2020),²⁰⁶ school buffer exclusion is the spatial restriction with strong policy support.^{206,216,221} Unfortunately, most established studies aimed at evaluating the plausible impacts of place-based spatial restrictions for availability reduction failed to link the changes in density with smoking.

Table 2.5 A summary of previous studies that examined the effectiveness of spatial restrictions

Area	Restriction type	Threshold	Effectiveness
San Francisco, the US	Capping	Cap 45 retailers per electoral district (2015). ^{206,215}	A 7.5% reduction in the total number of tobacco retailers across the city within 10 months of implementation. ^{206,215}
	Ban of sales	Ban tobacco sales in pharmacies (2012). ²¹⁶	The overall density reduction was 1.4 times as great as that in cities with no bans in pharmacies. ²⁰⁹
Santa Clara County, the US	Minimum spacing	New tobacco retailers are required to be a 500-ft minimum distance from another tobacco retailer, along with an annual fee of \$425 per tobacco retailer (2010). ²¹²	Resulted in 31% of tobacco retailers deciding to stop selling tobacco products. ²¹²
	School buffer exclusion zone	Prohibited tobacco retail licenses to any new retailer within 1000-ft of a K-12 school (2010). ²¹²	There were 3 out of 36 tobacco retailers decided to stop selling tobacco products after the implementation of the school buffer exclusion zone restriction. ²¹²
Philadelphia, the US	Capping	Cap one retailer per 1000 residents in each planning district of the city (2017). ^{206,207}	Resulted in a 9.8% decrease in the total number of issued tobacco retail licenses. ^{206,207}
New York City, the US	Ban of sales	Ban tobacco sales in pharmacies (2018). ²⁰⁸	Neighbourhood-level tobacco retail density decreased by 6.8%, with

			greater effectiveness in neighbourhoods with a higher proportion of Hispanics. ²⁰⁸
North Carolina, the US	Ban of sales	Ban tobacco sales in pharmacies (simulation) ²¹⁰	The pharmacy ban would approximately reduce tobacco retail density by 13.9% at the state level. ²¹⁰
	School buffer exclusion zone	A 1000-ft school buffer (simulation) ²¹⁰	The school buffer exclusion zone would reduce the overall tobacco retail density by 17.8% in North Carolina, the US. ²¹⁰
	Minimum spacing	A 500-ft minimum spacing between two neighbouring tobacco retailers (simulation). ²¹⁰	The overall tobacco retail density would be reduced by 22.1% at the state level. ²¹⁰
Missouri and North Carolina, the US	School buffer exclusion zone	350-, 500-, and 1000-ft school buffer zones (simulation). ²²⁰	Within 1000-ft school buffer zones, 22% of tobacco retailers in Missouri and 51% in New York could be reduced. ²²⁰

2.3.3 Equity impact of spatial restrictions

In addition to examining the effectiveness of spatial restrictions in reducing tobacco retail availability, a number of studies have evaluate the equity impacts of these spatial restrictions in the context of HICs.

Ribisl et al. (2017) examined the equity impact of 1000-ft school buffer exclusion zones in Missouri and New York, US.¹⁷¹ The school buffer exclusion zone reduced availability inequitably by income and race/ethnicity, with the greatest availability reduction in the lowest income quintile and in the highest quintile of the percentage of African Americans, suggesting the potential of school buffer exclusion zones in reducing tobacco retail availability and disparities in availability by income and race/ethnicity.¹⁷¹ Giovinco et al. (2018) tested the effectiveness of the tobacco-free pharmacy law using data in 2017.²⁰⁸ Banning tobacco sales in pharmacies could not only achieve an overall density reduction in tobacco retail by 6.8% but also had greater effectiveness in neighbourhoods with a higher proportion of Hispanics.²⁰⁸ In spite of the overall reduction in numbers of tobacco retailers across San Francisco after enforcing a series of spatial restrictions,^{206,215} Vyas et al. (2020) investigated the

efficacy of new policies in shaping the local densities of the tobacco retail environment but found no significant changes in the overall concentration of tobacco retailers by socioeconomic and ethnic types.¹⁷³

Furthermore, more advanced simulation methods have been used to examine the potential equity impacts of spatial restrictions for regulating tobacco supply. Findings from these simulation studies suggest that although place-based spatial restrictions are capable of reducing availability considerably, their impacts may differ by context.

Using an agent-based modelling approach, the Tobacco Town project evaluates the impact of different spatial restrictions on tobacco retail density reduction in the US.²²² Grouping neighbourhoods into 4 different town types, Luke et al. (2017)²²² and Comb et al. (2019)²²³ found the same policy scenarios resulted in distinct impacts on density reduction in different town types, suggesting the impacts of spatial restrictions are largely decided by the retail density at the starting points.²²² Luke et al. (2017) also revealed that availability reduction had a threshold effect on the total cost of obtaining cigarettes,²²² which may further suggest that reducing the number of tobacco retailers in high-density areas may have little effect on smoking rates unless the density could be reduced to a critical level.²²⁴ Using real retail data in 2017, simulated four major types of policy scenarios for availability reduction in Ohio. Craigmile et al. (2020) suggested that capping 1 tobacco retailer per 1000 people per census tract was the most effective policy scenario among all single spatial restrictions, which could result in a reduction of 29.6% of tobacco retailers.²¹³ Craigmile et al. (2020) further argued that the most impactful policy scenario depended on the context of the community and that school buffer exclusion zones are more equitable for low-income, African-American, and more urbanised neighbourhoods, while capping was more suitable for less urbanised neighbourhoods.²¹³ Marsh et al. (2020) examined the impact of “ban of sales” in the landscape of New Zealand, suggesting the socio-spatial inequalities in tobacco retail availability remained, although spatial restrictions could effectively reduce availability.²²⁵ Caryl et al. (2020) simulated 12 stakeholder informed plausible policy scenarios that were designed to reduce availability of tobacco retailers in the context of Scotland using the real retail data in 2016.²¹⁴ “Ban of sales” scenarios were found to have the greatest performance in reducing availability, followed by “minimum

spacing” scenarios.²¹⁴ However, the most effective policy scenarios in reducing availability also increased socioeconomic inequality.²¹⁴ Findings from these simulation studies indicated the impact of spatial restrictions on availability reduction and the inequality in availability may vary across contexts.

2.3.4 Spatial restrictions for regulating tobacco retail in China

Among the requirements for tobacco retail licensing, spatial restrictions for tobacco retail were designed and implemented at the local level (Tobacco Monopoly Bureau) under the national-level guidelines. Therefore, spatial restrictions for tobacco retail vary across geographic areas. Generally, 3 major types of spatial restrictions have been widely adopted in China for regulating tobacco supply (Table 2.6), including 1) school buffer exclusion zone; 2) minimum spacing; and 3) capping.

School buffer exclusion zone prohibits tobacco products from being sold around schools. Having been legislated nationally in 2021,²²⁶ the school buffer exclusion zone is the most important spatial restriction for tobacco retail with the aim of protecting students from earlier smoking initiation.²²⁷ The school buffer exclusion zone in megacities of China normally ranges from 50-100 m. Namely, it is 50 m-radius in Guangzhou,²²⁸ Chongqing,²²⁹ and Shanghai,²³⁰ but the prohibiting radius is 100 m in cities including Beijing,²³¹ Changsha,²³² and Hangzhou.²³³

Table 2.6 Enforced spatial restrictions in some megacities of China

City	School buffer exclusion zone	Minimum spacing	Capping
Beijing	100m	50m	A maximum of 7 tobacco retailers in each administrative village
Changsha	100m	-	1 tobacco retailer for every 50 households
Chongqing	50m	40m	-
Guangzhou	50m	-	-
Shanghai	50m	-	A maximum number of new tobacco retail licences was set within each district (abolished in 2018)

Minimum spacing and capping have also been frequently enforced in some cities of China. Minimum spacing requires a minimum distance between two neighbouring tobacco retailers (normally along the road). Enforced minimum spacing restrictions in megacities ranged from 40 to 50 m. In Chongqing,²²⁹ the threshold for minimum spacing is 40 m, while it is 50 m in other megacities including Beijing²³¹ and

Hangzhou.²³³ Although not as common as the other two types of spatial restrictions, capping is more widely used in the rural context of China. In the rural areas of Beijing,²³¹ each administrative village is capped with a maximum of 7 tobacco retailers, while every 50 households could be allocated 1 tobacco retailer in one administrative village in the rural areas of Changsha.²³² However, the effectiveness of these previously established spatial restrictions for regulating tobacco retail has not been fully examined even though these spatial restrictions have been implemented for years.

2.4 Conclusions: neighbourhood-level evidence from Chinese context

In addition to well-established evidence regarding the association between individual risk factors (e.g. SES, demographics, and mental health) and smoking behaviours, neighbourhood-level characteristics, such as neighbourhood advantage, tobacco retail availability, and place-based regulations, have been related to smoking through multiple pathways that link place and smoking. However, the limited evidence from LMICs is mixed and sometimes may reverse what has been documented in HICs (see section 2.1.3.1). Similarly, tobacco retailers were more likely to cluster within more deprived areas in HICs, but inconsistent findings were found in the same context as well, which requires more robust evidence, especially from the context of LMICs. As the biggest producer and consumer of tobacco worldwide, limited evidence regarding the tobacco retail environment and how local-level tobacco retail environments affect smoking behaviours as well as how policies may facilitate shaping the tobacco retail environment has been found in the Chinese context.

Although evidence examining the impact of neighbourhood deprivation and tobacco retail availability on smoking using longitudinal approaches is increasing, current findings regarding the association between neighbourhood deprivation, tobacco retail availability, and smoking largely depend on cross-sectional studies.¹²⁹ Compared with cross-sectional data where measurements are obtained at a single occasion, analysing longitudinal data where repeated measurements are made on the same subject over time could better reveal the causality by capturing the changes through time.^{234,235} Furthermore, there is still a lack of evidence regarding the impact of tobacco retail availability on smoking relapse,¹⁸⁷ while the impact of tobacco retail availability on smoking relapse also requires analysing longitudinal data. Therefore, to explore the causality between tobacco retail availability and smoking behaviours, particularly in China, analyses using longitudinal data are anticipated.

Additionally, previous longitudinal analyses on the neighbourhood effects of deprivation and tobacco retail availability on smoking mostly used cross-sectional environmental data and longitudinal behaviour data, the impacts of changing environments on smoking over time need more attention.

2.5 References

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Chapter 3 Data and methods

This chapter begins with a brief introduction of multiple datasets that were used in this thesis, followed by a description of spatial and statistical methods along with the analytic strategy.

3.1 Study Setting

Our study focused on the metropolitan area of Shanghai (Figure 3.1), which is the biggest megacity (6304.5 km²) of China. A total of 24.2 million people reside within 5,432 residential communities (akin to residential neighbourhoods, with an average population of 5,888) of Shanghai.



Figure 3.1 Administrative division of Shanghai at the residential community level

Multiple drivers, such as the historic legacy of a megacity, rapid urbanisation and social development, as well as the transition economy of Shanghai, contribute to the uneven urban development across the metropolitan area.^{1, 2} Based on established literature regarding Shanghai,^{2, 3} and delineated by the road network, Shanghai was classified into urban centre, urban area and suburb (Figure 3.2). Characterised by more economic activity and greater access to urban infrastructures and amenities, the urbanity level decreased from urban centre, to urban area, and to suburb.^{2, 4, 5}

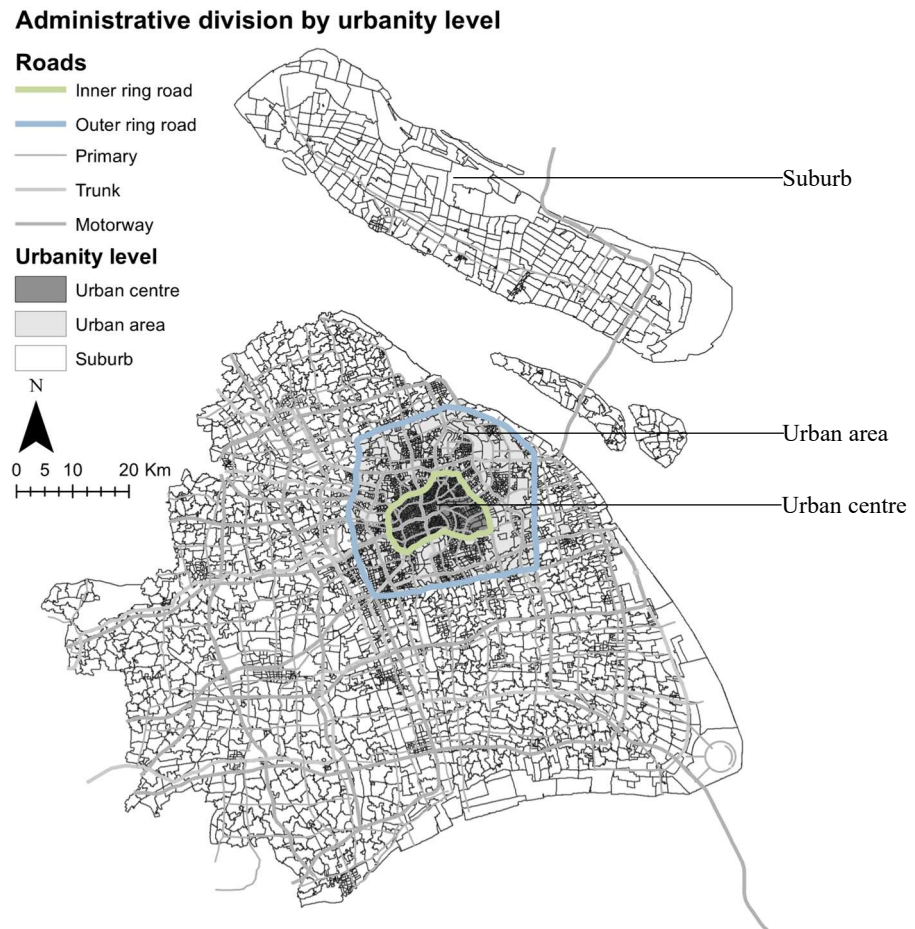


Figure 3.2 The metropolitan area of Shanghai by urbanity level

3.2 Data

Different types of data, including web-based data, administrative data, and panel survey data, were included in this thesis to investigate the research questions (Table 3.1). More specifically, Points of Interest (POIs) data and the road network data were obtained to represent tobacco retailers and the road network of Shanghai, respectively. Registered public school data was utilised to map the distribution of public schools and to represent the corresponding characteristics of public schools. Neighbourhood social environment variables were obtained from the 2010 Chinese population census. Individual-level data came from the International Tobacco Control China Survey (ITC China).

Table 3.1 Types of data and the corresponding chapter

Types	Data	Chapter
We-based data	Points of Interest (POIs)	Chapter 4-7
	Road network	Chapter 5
Administrative data	Registered public school list	Chapter 5
	2010 Chinese census	Chapter 4-7
Survey data	International Tobacco Control China Survey (ITC China)	Chapter 6

3.2.1. Web-based data

3.2.1.1 Tobacco retailer data

As the local authority overseeing tobacco retail, the Shanghai Tobacco Monopoly Bureau (TMB) holds the data on both legitimate and illicit tobacco retailers. However, the official data is not available for academic purposes. Therefore, in order to acquire data on tobacco retailers, web-based Points of Interest (POIs) data was utilised as an alternative to the registered tobacco retailer data. It is the most comprehensive and available open source data for analysing the spatial pattern of tobacco retailers in the Chinese context.

POIs are geographical entities represented by points that are related to people's daily lives,^{6, 7} including information regarding their name, type, and geocoordinates.⁷ POIs have been frequently used for spatial pattern analysis of retailers,⁶ amenities,⁸ and infrastructure.⁹ The enquiry of POIs is based on the POI database.⁷ In this thesis, the

POIs regarding tobacco retailers were sourced from Baidu Map, one of the biggest search engine bases and online map servers in China. The Baidu POI database contains a variety of types of services (Table 3.2). In this thesis, the POIs under the primary category “shopping services” regarding convenience stores, supermarkets, and tobacco and alcohol-only outlets were included to reflect the neighbourhood-level tobacco retail exposure through web-scraping using Ospider, a web-scraping tool (<https://github.com/skytruine/OSpider>). Specific details on data cleaning and validation will be introduced in Chapter 4.

Table 3.2 The categories of Baidu POIs. Adapted from Shen et al. (2022)¹⁰ and Baidu Map.¹¹

Primary category	Secondary Category
Catering services	Chinese restaurant, foreign restaurant, cafe, bar, etc.
Accommodation services	Star hotel, express inn, serviced apartment, etc.
Shopping services*	Shopping mall, department store, supermarket* , convenience store* , digital appliance, shop* , market, etc.
Domestic service	Post office, logistics company, ticket office, laundry, photo shop, real estate agency, public utility, maintenance point, housekeeping service, funeral service, lottery retailers, pet service, newsstand, public toilet, etc.
Beauty	Beauty, hairdressing, manicure, spa, etc.
Tourist attraction	Park, zoo, botanical garden, museum, aquarium, beach, church, etc.
Recreation and entertainment	Resort, cinema, KTV, theatre, ballroom, internet cafe, playground, massage, etc.
Sports and fitness	Stadium, extreme sports venue, fitness centre, etc.
Education and training	Higher education institution, secondary school, primary school, kindergarten, adult education, special education, research institution, training institution, library, etc.
Culture and media	Press and publishing, radio, television, galleries, exhibition, art centre, etc.
Medical care	General hospital, specialised hospitals, clinic, pharmacy, medical institution, sanatorium, emergency care service, etc.
Automobile service	Automobile sale, automobile maintenance, automobile beauty, automobile parts, car rental, etc.
Transportation	Airport, railway station, bus station, port, parking lot, gas station, bus routes, toll station, bridge, etc.
Finance service	Bank, ATM, investment and financing, pawn shop, etc.
Real estate	Office building, residential area, dormitory, etc.
Corporate business	Company, enterprise zone, etc.
Government agencies and organisations	Government agency, administrative authority, Public procuratorate and law institutions, etc.
Entrance and exit	Entrance of highway, exist of highway, entrance of airport, exist of airport, entrance of railway station, exist of railway station, etc.
Natural features	Island, hill, water, etc.
Administrative landmark	Province, provincial city, city, district, county, town, village, etc.
Address	Address, house number, etc.
Note: Bold* types of POIS that were involved in this thesis	

3.2.1.2 Road network data

Analysing spatial patterns through a network-based distance measure provides systematically better estimates than Euclidean distance measures.¹² The road network

data of Shanghai served as the basis of network analysis for Chapter 5, which aims to investigate the tobacco retail environment around public schools of Shanghai at 5 min and 10 min walking distances.

Data on the road network of Shanghai came from OpenStreetMap (OSM), which is one of the most popular geographic information platforms that works for Volunteered Geographic Information (VGI),^{13, 14} providing real-time updates and user-generated content related to its free global map services. OSM road network data benefits from its easy and efficient access to collecting updated data¹⁵ and has been used for a variety of Chinese studies, such as retail,^{16, 17} infrastructure,¹⁸ urbanisation and socioeconomic development.^{15, 19} The OSM road network in Shanghai has been assessed to have good quality in density and diversity.¹⁴

In the process of acquiring the road network, the keyword "highway" represents any kind of road, street, or path. In this thesis, under the category of highway, sub-categories including "motorway", "trunk", "primary", "secondary" were acquired to reflect the whole structure of the road network of Shanghai. In addition, sub-categories, including "territory", "unclassified", and "residential", were acquired to provide more details that reflect possible walking routes.²⁰

Table 3.3 Types of roads (“highway”) in OSM. Sourced from Wikipedia.²⁰

Types of roads (“highway”)	Definitions
Motorway	A restricted access major divided highway, normally with 2 or more running lanes plus emergency hard shoulder.
Trunk	The most important roads in a country’s system that are not motorways.
Primary	The next most important roads in a country's system for larger towns
Secondary	The next most important roads in a country's system for link towns
Tertiary	The next most important roads in a country's system for smaller towns and villages
Unclassified	The least important through roads in a country’s system
Residential	Roads that are linked with housing.

3.2.2 Administrative data

3.2.2.1 Public school data

All Chinese citizens must accept school education for a minimum of nine years funded by the government (i.e. nine-year compulsory education). Enrolment in public schools

for primary and middle school education (Years 1-9) is based on proximity²¹ and whether their *hukou* (the household registration system of China) are registered within the school catchment areas.²² While the enrolment of public high schools (Years 10-12) is decided by academic performance and *hukou* registered district. There is no such restriction for private schools. Researchers suggest unequal access to high-quality public education resources may induce social inequalities by school catchment areas.²¹,²² Considering the statistics that 90% of all pupils aged 6-18 enrolled in public schools in Shanghai in 2018,²³ to simplify the research process as well as to capture the potential disparities in the tobacco retail environment by types of school catchment areas, only public school data from Shanghai was included in this thesis.

In Chapter 5, the registered public school list sourced from the official website of the local educational department of Shanghai was utilised to examine the tobacco retail environment around public schools in shanghai.²⁴⁻²⁶ Due to the availability of open source data, this thesis only considered public schools with published enrollment plans in 2019 (n = 1,483).

Table 3.4 Education system and the corresponding public school types in Shanghai

School years	Age	School types				
Year 1	6-7	Primary school (n=702)			9/12-year school (n=120)	
Year 2	7-8					
Year 3	8-9					
Year 4	9-10					
Year 5	10-11					
Year 6	11-12	Middle school (n=354)		Secondary school (n=98)		
Year 7	12-13					
Year 8	13-14					
Year 9	14-15					
Year 10	15-16	High school (n= 129)				
Year 11	16-17					
Year 12	17-18					

3.2.2.2 Neighbourhood social environment data

Variables representing the neighbourhood social environment were sourced from the 2010 Chinese population census at the residential community level. The 2010 Chinese census covered a total of 1.34 billion people from 400 million households.²⁷ It is the most comprehensive and detailed administrative data in China. During the enumeration, a short form and a long form were included in the census (Table 3.5).

The short form covered the standard sociodemographic information (e.g. age, sex, *hukou* registration, and education level).²⁸ While the long form enumerated 10% of the households in most provinces, it provides a range of additional information (e.g. housing conditions).²⁸ The descriptive statistics on census variables about housing conditions were presented in Table 3.6.

Table 3.5 Items included in the 2010 Chinses census. Adapted from Wu and He (2015).²⁸

	Short form	Long form
Address		Building number
Household ID	H	H
Household type	H	H
Number of people qualified for enumeration (by sex)	H	H
Number of births and deaths within a year, by sex	H	H
Housing conditions		
Number of rooms	H	H
Floor area	H	H
Use		H
Building year		H
Number of stories		H
Outside decoration/ structure type		H
Kitchen		H
Tapping water		H
Bathing		H
Toilet		H
Source of housing		H
Purchase price		
Rent		H
Name	R	R
Relationship to household head	R	R
Sex	R	R
Birth year and month	R	R
Nationality	R	R
Current residence		
<i>Hukou</i> registration place	R	R
<i>Hukou</i> Registration type	R	R
Birth place country		R
Residence 5 years ago		R
Education		
Illiterate or not	R	R
Education level	R	R
School enrolment status		R
Employment and working hours		R
Source of living income		R
Marital status		R
Year/month of first marriage		R
Number of births and surviving births, by sex		R
Number of births within a year (women aged 15-50)		R
Health status (aged 60 or above)		R

Note: H and R stands for the labels of items for the households and individuals, respectively

Table 3.6 Descriptive statistics on census variables about residential community-level housing conditions by levels of urbanity and across Shanghai

Housing conditions	Description	Mean (SD)			
		Urban centre	Urban area	Suburb	Overall
Number of rooms (categorical)	Proportion of households living within one room per residential community (%)	46.10 (0.80)	34.50 (0.54)	36.39 (0.54)	37.49 (0.36)
Floor area (categorical)	Proportion of households living within less than 30 m ² per residential community (%)	29.49 (0.82)	15.39 (0.57)	29.40 (0.57)	24.37 (0.38)
Kitchen (categorical)	Proportion of households without kitchen per residential community (%)	14.80 (0.69)	15.39 (0.57)	28.40 (0.57)	24.37 (0.38)
Tapping water (categorical)	Proportion of households without tapping water per residential community (%)	5.76 (0.42)	4.89 (0.32)	8.50 (0.31)	6.84 (0.20)
Bathing (categorical)	Proportion of households without bathing equipment per residential community (%)	24.23 (0.92)	12.90 (0.55)	32.25 (0.54)	24.56 (0.38)
Toilet (categorical)	Proportion of households without toilets per residential community (%)	20.51 (0.95)	9.00 (0.49)	17.22 (0.45)	15.13 (0.33)
Source of Housing (categorical)	Proportion of residents who are tenants (%)	44.75 (0.91)	29.49 (0.50)	36.80 (0.52)	35.83 (0.35)

To capture the characteristics of neighbourhood social environment in Shanghai, as presented in Table 3.7, the construction of deprivation index followed previous studies in China^{29,30} and international establishments such as Townsend³¹ and Carstairs.³² The unemployment rate was included across four different indices. Low-social class/ low-end occupation and non-homeownership were included by the Carstairs index and two Chinese context indices. Overcrowding is a popular indicator in the context of Western countries. However, due to the availability of data from the Chinese census at the residential community level, overcrowding cannot be assessed. Although the census provides data on the number of rooms per household and floor area per household, the household size variable is not available for computing at the residential community level. Therefore, as another popular indicator that has been adopted in both Chinese indices,^{29,30} non-home ownership/home ownership was included along with education,

employment, and working (employment and occupation) were selected to construct the deprivation index in Shanghai, China (Table 3.8).

Table 3.7 Comparison of established deprivation indices

Established indices	Context	Indicators			
Carstairs ³²	UK	Lack of car ownership	Local social class	Male unemployment	Overcrowding
Townsend ³¹	UK	Non-car ownership	House overcrowding	Unemployment	Non-home ownership
Huang et al. (2018) ²⁹	China	Education	Low-end occupation	Unemployment	Non-homeownership
Liu et al. (2018) ³⁰	China	Education	Low-end occupation	Unemployment	Homeownership

Table 3.8 Census data to deprivation index

Indicator	Definition	Variables from the census	Calculation
Unemployment rate (%)	Percentage of unemployed residents.	Reason for not working Working condition	(Unemployed because of employers' reason + unemployed because of personal reason + Contracted land is expropriated)/(unemployed because of employers' reason + unemployed because of personal reason + Contracted land is expropriated + working more than 1 hour last week + temporarily on leave or studying)
Low-skilled workers rate (%)	Proportion of residents who are blue-collar worker and pink-collar worker.	Occupation category	(Service personnel + production personnel + operators and related personnel)/samples
Education of junior high or below (%)	Proportion of residents with education of junior school or below.	Education level	(No school attainment + primary school + junior school)/samples
Non-homeownership rate (%)	Proportion of residents who are tenants.	Housing condition	(without own property)/samples

3.2.3 Longitudinal survey data - Individual data

Individual-level data for this thesis was acquired from the International Tobacco Control China Survey (ITC China), which is a longitudinal survey focused on smoking behaviours among adults in China.³³ The ITC Projects were created in 2002, aimed to measure the effectiveness of national-level tobacco control policies in countries that

signed and ratified the Framework Convention on Tobacco Control (FCTC), first started in four countries, including Canada, the US, Australia, and the UK.³⁴ The ITC China survey was launched in 2006 as one of the most significant expansions of the ITC Project. It intends to evaluate and understand the psychosocial and behavioural effects of national-level tobacco control policies of the FCTC in the Chinese context.³³ Between 2006 and 2015, ITC China, in collaboration with the Office of Tobacco Control of China CDC, conducted 5 waves of surveys among adult smokers and never-smokers in selected cities of China (Table 3.9), including Shanghai (Table 3.10).^{34,35} The cohort design of the ITC China allows researchers to understand the changes in smoking behaviours and their association over time with policies.³³

Table 3.9 An overview of ITC China. Adapted from ITC Project (2017)³⁵ and ITC Project (2021).³⁶

Wave	Survey dates	Survey sample size	Survey cities
Wave 1	2006	6,001 (4,732 smokers and 1,269 never-Smokers)	Beijing, Changsha, Guangzhou, Shanghai , Shenyang, Yinchuan
Wave 2	2007-2008	6,064 (4,626 smokers, 363 quitters, and 1,121 never-Smokers)	
Wave 3	2009	7,001 (5,258 smokers, 326 quitters, and 1,417 never-Smokers)	Beijing, Changsha, Guangzhou, Shanghai , Shenyang, Yinchuan, Kunming
Wave 4	2012	6,981 (5,281 smokers, 278 quitters, and 1,422 never-Smokers)	
Wave 5	2013-2015	9,880 (7,583 smokers, 234 quitters, and 2,063 never-Smokers)	Beijing, Changsha, Guangzhou, Shanghai , Shenyang, Yinchuan, Kunming, Changzhi, Huzhou, Tongren, Yichun, Xining
Survey mode: face-to-face interview			
Note: Bold indicates data included in this thesis.			

Table 3.10 Sample size of ITC China Wave 1-5 in Shanghai. Adapted from ITC Project (2017).³⁵

	Wave 1 (n)		Wave 2 (n)		Wave 3 (n)		Wave 4 (n)		Wave 5 (n)	
	Smokers	Never-smokers	Smokers	Never-smokers	Smokers	Never-smokers	Smokers	Never-smokers	Smokers	Never-smokers
Shanghai	784	204	803	204	784	204	808	203	815	205

The ITC China used a stratified multistage cluster sampling design, where each city is treated as a stratum.³³ A total of 800 adult smokers and 200 adult never-smokers from 6000 households in 20 selected residential communities were surveyed for each city.³³ Replenishment samples were collected following the existing sample frame.³³

In addition to the collection of individual sociodemographic data such as age, sex, education, and income, a major objective of the ITC China is to measure important smoking and smoking-related behaviours (Table 3.11).³⁴ The ITC China provides appropriate individual data for studying neighbourhood effects on smoking and smoking cessation, which could be further linked at the residential community level of Shanghai.

Table 3.11 Individual-level variables drawn from the ITC China. Data derived from ITC Project (2017).³⁵

Type	Variables	Comments
Outcome	Never-smoker	
	Current smoker	Non-daily smoker
		Daily smoker
	Quitter	Quitters with shorter duration of abstinence Quitters who has quitted since the last wave
Covariates	Sex	Male versus female
	Age	Years
	Education	None
		Primary school
		Middle school
		High school, vocational school
		College
		University or higher
	Household income per month	<1000 (CNY)
		1000-2999 (CNY)
		3000-4999 (CNY)
		5000-6999 (CNY)
		7000-8999 (CNY)
		9000+ (CNY)
		Not stated

3.3 Spatial Analysis

This section provides an introduction to spatial analysis approaches adopted in the empirical chapters of this thesis. Different point pattern analyses, including kernel density estimation (KDE), network-based service area analysis, and spatial cluster analysis, were applied to estimate the tobacco retail availability within residential neighbourhoods (Chapters 4, 6, and 7), and the spatial patterning of tobacco retailers around school environments (Chapter 5). Spatial thinning approaches were applied to simulate spatial restriction scenarios that aim at reducing tobacco retail availability in Chapter 7.

3.3.1 Kernel density estimation (KDE)

Kernel density estimation (KDE) was performed to assess the neighbourhood-level tobacco retail availability in Shanghai. KDE is a non-parametric technique of extrapolating point data over an area of interest.³⁷ As an important method for mapping spatial point patterns, KDE has been widely used for measuring environmental exposure to health, particularly in healthcare facilities,³⁸ alcohol and tobacco retail,³⁹⁻⁴³ and others. A major advantage of KDE is its capability of providing density estimation at any location by transforming all point events into a smoothed, continuous surface with no constraints.^{37,40} By representing the number and proximity of point events within the search radius, KDE can provide a spatial-weighted estimate of density by placing greater weights on those points close to the centre.⁴⁰ The KDE was performed in ArcGIS 10.7.1, where the built-in KDE tools adopt the Quartic kernel function to calculate the tobacco retail availability based on the point patterns of POIs regarding tobacco retailers.^{44,45}

Further, to measure the neighbourhood-level tobacco retail availability, the KDE values of the cells of the geometric centroids of subcommunities were aggregated to the community level, which represents the number of tobacco retailers per km². Chapter 4 provides a more detailed introduction to using population-weighted KDE to measure neighbourhood-level tobacco retail availability.

3.3.2 Network analysis

The Geographic Information System (GIS) provides a set of powerful tools for analysing spatial data.⁴⁶ Based on the ArcGIS platform, the built-in Network Analyst extension allows for building a network dataset and performing analyses on a network dataset. Compared to buffer analysis, which uses the conventional search function based on Euclidean distance, a network-based service area approach can provide a more realistic estimation by following the shortest path along the segments of the network.⁴⁷



Figure 3.3 Illustration on network-based service area analysis

In this thesis, service area analysis was performed using Network Analyst of ArcGIS 10.7.1 to examine the distribution of tobacco retailers around public schools. The service areas with multiple radiuses were generated around the main entrances of public schools based on the road network of Shanghai. The number of tobacco retailers that fell within the service areas was calculated to describe the distribution of tobacco retailers.

3.3.3 Spatial cluster analysis

Spatial cluster analysis, also known as K-function analysis, is another important method for point pattern analysis. Unlike KDE, which describes the density varying across a geographical area of interest,³⁷ K-function has advantages in describing characteristics of the point patterns (i.e. univariate, bivariate, and multivariate) at many distance scales.⁴⁸ Summarise the number of point events up to a given distance from a point event. The generalisation of K-function is given by (1):

$$K_{ij}(r) = \lambda_j^{-1} E[N_r] \quad (1)$$

Where $E[.]$ is expectation, N_r represents the number of type j events within distance r of a randomly chosen type i event, λ is the density (number per unit area) of events.

In Chapter 5, which examined the degree of spatial clustering of tobacco retailers around public schools, bivariate and multivariate K-function analyses were conducted to examine whether and to what extent tobacco retailers were clustered around schools and whether the clustering pattern differed by types of tobacco retailers. All analyses were conducted using spatstat "Kcross" and "Kdot" functions in the R environment. under complete spatial randomness (CSR), which could be simplified as $K_{ij}(r) = \pi r^2$,⁴⁸ using Ripley's edge correction to adjust the points at the boundary of study setting.^{48,49}

3.3.4 Spatial thinning

Spatial thinning approaches have been frequently applied to reduce the impact of geographical sampling bias for modelling species niches and their associated geographical distributions, particularly in biogeographic-related studies.⁵⁰ In Chapter

7, spatial thinning approaches were performed to construct simulation scenarios aimed at reducing tobacco retail availability.

In general, the two major types of spatial thinning approaches include randomly sampling a set number of point patterns and thinning point patterns based on nearest neighbour distance.⁵⁰ In Chapter 7, two types of spatial thinning approaches were both applied to simulate spatial restrictions for tobacco retail availability reduction. Namely, a randomly sampling approach was applied to simulate the scenario that requires reducing the total number of tobacco retailers to a certain proportion of the baseline using the spatstat "rthin" function in the R environment, while the spThin "thin" function was applied to randomly remove tobacco retailers at given thinning distances in the R environment for simulating the minimum spacing scenarios. Both of these functions from two different R packages were each capable of stochastically removing a set of point patterns (i.e. tobacco retailers) and generating multiple new subsets that meet the constraints of the stratified random sampling strategy (i.e. spatstat "rthin") and nearest neighbour distance (i.e. spThin "thin") correspondingly.

3.4 Statistical Analysis

This section provides a brief theoretical demonstration of the statistical analyses which were used in four empirical chapters of this thesis. Table 3.10 lists the statistical analyses that were applied in this thesis and their corresponding chapters. The detailed implementation of the statistical analyses are further described in Chapter 4-7.

Table 3.12 Statistical analysis and the corresponding chapter

Chapter	Statistical analysis
Chapter 4	Kruskal-Wallis test and effect size estimation (i.e. Epsilon squared)
Chapter 6	Multilevel modelling (i.e. 2-level logistic regressions) and Generalised Estimating Equations
Chapter 7	Kruskal-Wallis test and effect size estimation (i.e. Epsilon squared)

3.4.1 Kruskal-Wallis test

The Kruskal-Wallis is a non-parametric test that assesses the differences among more than two independently sampled groups on a single, non-normally distributed continuous variable.^{51,52} It is an extension of the two-group Mann-Whitney U (Wilcoxon rank) test and it is the non-parametric equivalent of the one-way Analysis of variance (ANOVA).⁵² Without assuming the distribution of the data, ranks are compared rather than group means.⁵² The null hypothesis of the Kruskal-Wallis test is that the medians of all groups are equal. To test the null hypothesis, groups of variables of interest are combined into a single group and ranked.⁵² The significant statistic suggests at least one sample stochastically differed from another sample. The Kruskal-Wallis test has been applied in studies such as mental health status,⁵³ physical activity,⁵⁴ the spatial patterning of forests.⁵⁵ Reflecting the variance in ranks between groups and closely resembling the chi-square distribution, H is given by (2):⁵²

$$H = \frac{N-1(gn_n(t_i-T_i)^2)}{gsn_n(t_j-T_i)^2} \quad (2)$$

where n_n is the sample size of the corresponding group, g is the sum of the group n , sn_n is the sum of the corresponding group n , t_i is the average observed rank sums for the group, t_j is the observed rank for an observation for the corresponding group, and T_i is the observed total average rank sums.

In this thesis, the Kruskal-Wallis test was performed to examine the difference in tobacco retail availability by levels of neighbourhood deprivation in 2019 (Chapter 4) and after applying a series of simulation scenarios aimed at reducing tobacco retail availability (Chapter 7).

3.4.2 Effect size estimation

An effect size is the magnitude of the difference between groups.⁵⁶ The results of the Kruskal-Wallis test indicate whether there are differences among the groups, but not how strong the differences are. Therefore, the effect size is critical to be reported along with the Kruskal-Wallis test to reflect the strength of the relationship between variables.⁵⁷

A number of effect size estimates for statistical tests have been developed. Epsilon squared is among the most common statistics for the Kruskal-Wallis test, which was calculated by (3):⁵⁷

$$\varepsilon^2 = \frac{H}{(n^2-1)(n+1)} \quad (3)$$

Where H is the value obtained in the Kruskal-Wallis test, n is the total number of observations, ε^2 is the coefficient assumes the value from 0 (no relationship) to 1 (perfect relationship).

In this thesis, effect size estimation using epsilon squared was performed along with the Kruskal-Wallis test in examining the magnitude of the impact of neighbourhood deprivation on tobacco retail availability in Chapter 4. In Chapter 7, using the same approaches as in Chapter 4, the Kruskal-Wallis test and effect size were applied to examine whether social inequality in accessing tobacco retailers increased or not after imposing simulated spatial restrictions for reducing tobacco retail availability.

3.4.3 Two-level logistic regressions

Multilevel models (MLMs) are statistical models that are particularly appropriate for clustered data, which are also known as mixed-effect models and hierarchical linear models.^{58,59} This approach involves at least two levels of relationships among

variables.⁶⁰ Data used a stage sampling strategy, such as panel survey data, which has individuals clustered within geographical units (i.e. residential neighbourhoods). By allowing for the simultaneous examination of the cluster-level and individual-level effects on individual outcomes while accounting for the non-independence of observations within groups, MLMs can be used to draw inferences regarding the potential causes of within-group variation and between-group variation.^{61,62} Therefore, an increasing body of research has examined neighbourhood-level characteristics in relation to individual-level outcomes using MLMs,^{62,63} particularly in research regarding smoking, for both continuous (e.g. cigarettes consumption, smoking intensity)^{64,65} and binary outcomes (e.g. smoking versus quitting).⁶⁶⁻⁶⁸

In Chapter 6, two-level logistic regressions, a specific type of MLMs for binary outcomes, were applied to examine the cross-sectional impacts of tobacco retail availability and neighbourhood deprivation on binary outcomes regarding smoking and smoking cessation. The generalised formula for a 2-level logistic regression model is given by (4):⁶⁹

$$\text{Logit} \left(\frac{\pi_{ij}}{1-\pi_{ij}} \right) = Y_{ij} = \beta_0 + \beta_1 \text{Age}_{ij} + \beta_2 \text{Edu}_{ij} + \beta_3 \text{Inc}_{ij} + \beta_c X_{ij} + u_j \quad (4)$$

where the log odds of binary outcomes (e.g. current smoking versus current non-smoking) is denoted by Y_{ij} for individual i in community j . Y_{ij} is a function of an intercept β_0 , a set of individual-level factors ($\beta_x x_{ij}$), a vector of community-level characteristics ($\beta_c X_{ij}$) representing neighbourhood-level tobacco retail availability or neighbourhood deprivation, u_j is the variability of the individuals across clusters (i.e. the level-2 residual).

3.4.4 Generalised estimating equations

Generalised estimating equations (GEEs), also known as population average models or marginal models, are used to estimate parameters of the generalised linear model with a possible unknown correlation between outcomes.^{70,71} GEEs describe changes in the population mean gives changes in covariates, while accounting for within-cluster non-independence of observations when deriving the variability estimates of these coefficients.⁶² As summarised by Hubbard et al. (2010) and Subramanian and

O'Malley (2010), the focus of GEEs is to estimate the average response over the population rather than the regression parameters that would enable prediction of the effect of changing one or more covariates on a given individual.^{62,72} Under specific circumstances, the estimates provided by a GEE approach and a MLM approach were the same.⁶² GEEs sometimes provide practically the same estimator of the parameters to MLMs.⁶² Unlike MLMs, GEEs involve fewer assumptions and do not require knowledge of the ways in which individuals are correlated within a neighbourhood nor on how neighbourhoods vary.⁷² The generalised formula of GEE is expressed as (5):⁷³

$$\text{logit}\{E(Y_{it})\} = x_{it}\beta, \quad Y \sim \text{Bernoulli} \quad (5)$$

where Y_{it} is the binary outcome regarding smoking or smoking cessation (e.g. current smoking versus current non-smoking) for individual i in wave t , with expected value $E(Y_{it})$ and covariates or explanatory variables x_{it} , β is the regression coefficient.

Due to the size of the sample used in Chapter 6 is not sufficient enough for a 3-level logistic regression to examine the impacts of tobacco retail availability and neighbourhood deprivation on smoking and smoking cessation over time, following prior research using the same dataset,⁷⁴ the GEEs were applied to examine the average impact of tobacco retail availability and neighbourhood deprivation on smoking and smoking cessation over time.

3.5 Analytic Strategy

To answer research questions, spatial and statistical analyses were performed to analyse different datasets of Shanghai, including tobacco retailers, public schools, neighbourhood and school deprivation, as well as individual data. The analytic strategies for each of the empirical chapters were described (Figures 3.4-3.7).

In Chapter 4 (Figure 3.4), KDE was performed to calculate the smoothed density of tobacco retailers represented by the POIs, across Shanghai, further using population-weighted KDE to calculate the neighbourhood-level tobacco retail availability. Using data extracted from the 2010 Chinese census, the neighbourhood-level socioeconomic variables were summed up to the neighbourhood deprivation index after standardising using z-scores. The Kruskal-Wallis test was performed to examine whether there were statistical differences in neighbourhood-level tobacco retail availability by levels of neighbourhood deprivation, while effect size, calculated by the epsilon squared, was applied to assess the impact of levels of neighbourhood deprivation on tobacco retail availability. All analyses were stratified by types of tobacco retailers and levels of urbanity.

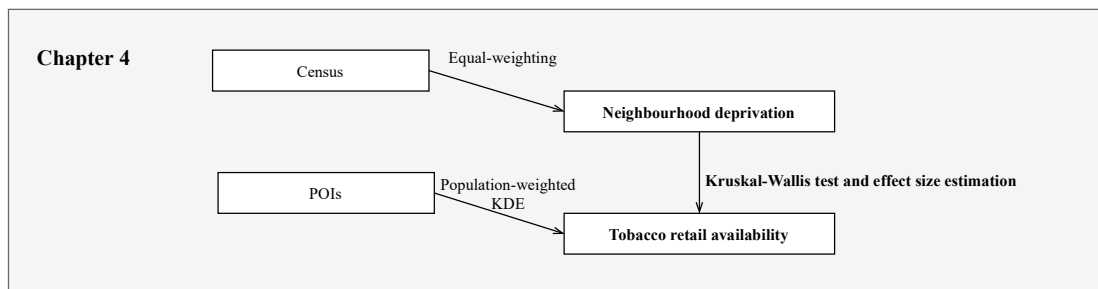


Figure 3.4 Analytic strategy in Chapter 4

In Chapter 5 (Figure 3.5), POIs regarding tobacco retailers and public schools of Shanghai were mapped with the road network of Shanghai in ArcGIS. Network-based service area analysis was performed to examine the distribution of tobacco retailers around public schools in Shanghai by calculating the number of tobacco retailers falling within service area buffers at distances of 400 m and 800 m walking distance from the main entrance of a public school. Network-based service area analysis also served for the examination of the compliance of tobacco retailers around public schools by examining the proportion of public schools in the vicinity of a tobacco

retailer within 50 m and 100 m distances. Finally, spatial cluster analysis, bivariate and multivariate K-function, were both applied to examine whether tobacco retailers were clustered around public schools of Shanghai. All analyses were stratified by types of public schools, levels of urbanity, levels of school deprivation, and types of tobacco retailers.

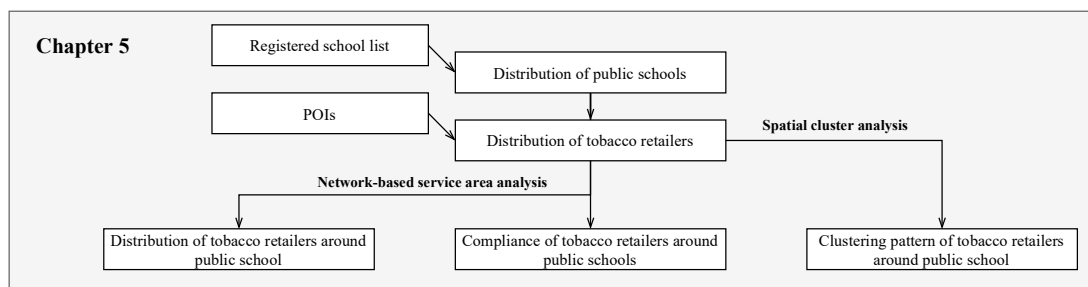


Figure 3.5 Analytic strategy in Chapter 5

In Chapter 6 (Figure 3.6), tobacco retail availability and the neighbourhood deprivation index (constructed in Chapter 4) were linked with male samples of Shanghai sourced from the ITC China survey at the residential community level. With and without the adjustment of individual covariates, two-level logistic regressions were applied to examine whether tobacco retail availability and neighbourhood deprivation were each associated with smoking and smoking cessation cross-sectionally, while GEEs were applied to determine whether tobacco retail availability and neighbourhood deprivation were each associated with smoking and smoking cessation over time. Furthermore, the impact of tobacco retail availability on smoking and smoking cessation was tested by levels of urbanity and levels of neighbourhood deprivation, cross-sectionally and longitudinally. Additionally, a sensitivity analysis was performed for the full sample that included both genders of Shanghai.

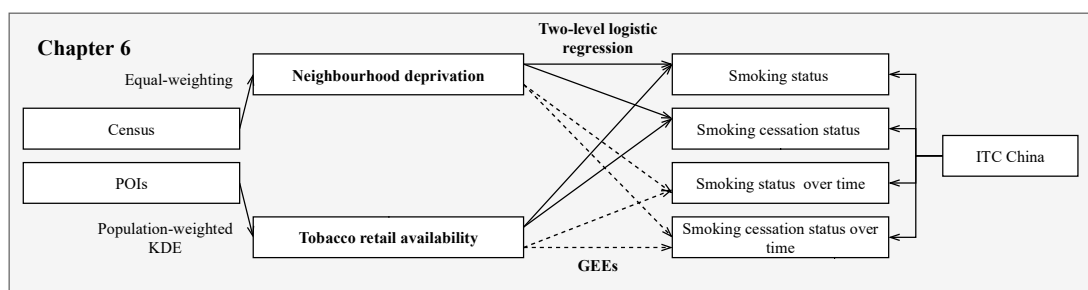


Figure 3.6 Analytic strategy in Chapter 6

In Chapter 7 (Figure 3.7), informed by key-stakeholders from China and established evidence regarding spatial restrictions for availability reduction, a total of 12 simulation scenarios aimed at reducing tobacco retail availability were created using spatial thinning approaches and buffer analysis. The data used in Chapter 4 was treated as the baseline, and following the measures that have been used in Chapter 4, the population-weighted KDE was applied to measure the neighbourhood-level tobacco retail availability after implementing simulated spatial restrictions. The Kruskal-Wallis test was performed to examine whether availability of tobacco retailers differed by levels of neighbourhood deprivation in simulation scenarios, while the effect size was calculated to identify the changes in social inequality in tobacco retail availability.

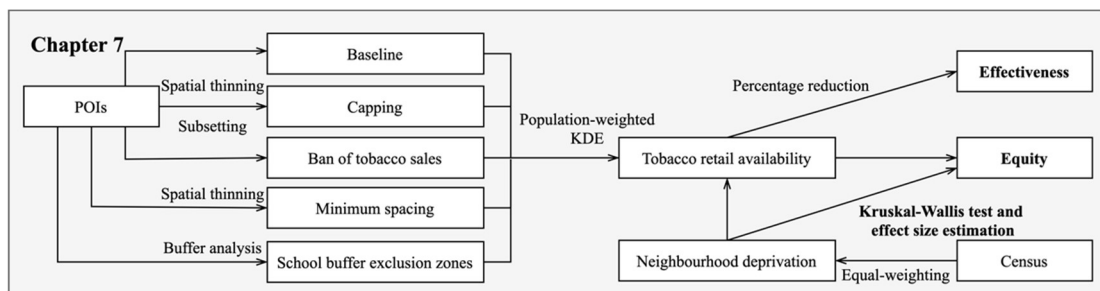


Figure 3.7 Analytic strategy in Chapter 7

3.6 References

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Chapter 4 A cross-sectional analysis of socio-spatial patterning of tobacco retail in Shanghai, China

4.1 Abstract

Introduction. International evidence from high-income countries demonstrates that the availability of tobacco tends to be greater in more urban and more deprived neighbourhoods. However, little is known about the socio-spatial disparities in other settings, including megacities in China. This study investigated the patterning of tobacco retailers across Shanghai by types of tobacco retailers, including the relationship with levels of urbanity and neighbourhood deprivation.

Methods. Tobacco retailer data ($n = 19,413$) was extracted from a web-scraped Points-of-Interest database. For all communities ($n = 5,432$) across Shanghai, neighbourhood tobacco retail availability was calculated using population-weighted kernel density estimation and grouped by quintiles of neighbourhood deprivation and a 3-level urban classification. Associations were analysed using the Kruskal-Wallis test and epsilon-squared.

Results. Across Shanghai, tobacco retail availability decreased from more urbanised areas to less urbanised areas. There was a statistical difference ($p < 0.001$) in the availability of tobacco retail across quintiles of deprivation, with the highest availability in the less deprived neighbourhoods and the lowest availability in the most deprived neighbourhoods. However, this trend was reversed in the urban centre, where retail availability was greatest in the most deprived areas. Convenience stores were the most common type of tobacco retailer across the city, while tobacco-only outlets were most strongly associated with levels of neighbourhood deprivation.

Conclusion. The results show an association between tobacco retail availability and neighbourhood deprivation, which varied with levels of urbanity and types of tobacco retailers. These findings provide supportive evidence for further interventions that target reducing inequalities in exposure to tobacco retail.

Implication. This is the first study to examine the relationship between tobacco retail availability and neighbourhood deprivation in the context of Chinese megacities. Using data from Shanghai, China, we found a significant non-linear association between tobacco retail availability and neighbourhood deprivation across the city. It is

plausible that the socio-spatial disparities in tobacco retail availability at the neighbourhood level may be a key factor explaining differences in smoking behaviours between sociodemographic groups. The findings emphasize need for greater efforts in regulating neighbourhood-level tobacco retailing in China.

4.2 Introduction

China is the largest tobacco manufacturer and consumer worldwide, accounting for 30% of the world's tobacco production and 40% of the tobacco consumption, with more than 300 million current smokers.¹ In 2018, the smoking prevalence in China was 26.6% (50.5% among men and 2.1% among women).² More than 1.4 million cases of premature mortality can be attributed to smoking-related diseases every year.³ Given the high prevalence of smoking and the tremendous burden of tobacco-related diseases, the development of successful tobacco control policies is a key public health priority in China.

In addition to individual-level factors (e.g. socioeconomic status,⁴ gender,⁵ mental health status⁶), previous international research has demonstrated that a number of local environmental factors (e.g. neighbourhood disadvantage,^{7, 8} local social norms,⁹ neighbourhood crime,¹⁰ disorders and stressors⁸) explain the social and spatial differences in smoking behaviours. Tobacco retail availability has also been identified as a key environmental factor that likely contributes to tobacco consumption.^{7, 11, 12} Better access to tobacco retailers, such as higher density or closer residential proximity, can promote smoking by providing opportunities to obtain products, raise tobacco brand awareness, create a competitive local market that might reduce product costs, and influence social norms regarding tobacco consumption.¹³ Prior studies from North America, the UK, and New Zealand suggest an association between better tobacco retail availability and a higher chance of smoking initiation among adolescents,^{14, 15} higher adult smoking prevalence,^{11, 12} and lower odds of cessation,^{12, 16, 17} emphasising the importance of regulating tobacco retail availability as part of a comprehensive tobacco control strategy.¹⁷

The tobacco industry strategically targets low-income, disadvantaged, and minority populations.¹⁸ Studies from high-income countries (HICs), including the US,^{19, 20} Canada,²¹ Australia,²² New Zealand,²³ and Scotland,²⁴ show that tobacco retailers tend to concentrate in more deprived,²¹⁻²⁴ more urbanised,^{19, 24} or high-minority neighbourhoods.^{19, 20} Residents living in deprived communities may have limited information about the health hazards of smoking, as well as a lack of social support

and resources (e.g. healthcare, employment opportunities), which increases their susceptibility to taking up smoking^{25, 26} and is likely to result in greater disparities in tobacco use and subsequent health outcomes.²⁶

Although strong social gradients in tobacco retailing have been found in HICs, little research has been carried out on the socio-spatial patterning of tobacco retailing in other settings, including urban China,²⁷ where tobacco retailing remains ubiquitous.²⁸ ²⁹ Previous work on tobacco retailing in China, such as a study in Hangzhou,²⁸ has relied on audit sampling to acquire data on tobacco retailers, which is likely to lead to incomplete and potentially biased information that underestimates the retail distribution, particularly in less urbanised areas. Another study in Changsha relying on audit sampling, found a positive but non-significant association between the total number of tobacco retailers within each neighbourhood and the average property price in the neighbourhood.³⁰ Similarly, Wang et al. (2016) demonstrated that illicit tobacco retailers tended to be concentrated in the urban centre and in high population density areas.²⁷

Therefore, there is a need for a more robust evidence base examining the social patterning of tobacco retailing in China. Many of the factors driving the socio-spatial distribution of tobacco retailing in HICs have become increasingly pertinent in the Chinese context, particularly over a period of dramatic urban transformation that has fundamentally changed the community structures and social order of Chinese cities.³¹ These rapid urban changes have been accompanied by shifts in tobacco use, including the concentration of smoking among more disadvantaged groups.^{31, 32} Further, growing inequalities in land prices and rental costs in urban China may lead to a preponderance of tobacco retailing in more deprived areas, and in turn a greater concentration of smokers in less advantaged neighbourhoods.³³ Given the rapid transformation of the economy and its urban form, we hypothesised that the socio-spatial patterning of tobacco retail in the megacity of Shanghai may share similarities with those documented in HICs.

The State Tobacco Monopoly Administration (STMA) is the governmental body that oversees the availability of tobacco in China.^{34, 35} The local branch of STMA, the Shanghai Tobacco Monopoly Bureau (TMB), is authorised to design, implement, and

enforce zoning regulations regarding tobacco retail under the national guidelines. In China, and Shanghai in particular, various tobacco control policies similar to those of HICs have been introduced in recent years, including smoke-free environments at Expo 2010, which was the first local-level legislation on tobacco control in China that prohibits smoking in 13 kinds of public spaces.³⁶ Furthermore, interventions less common in HICs have also been introduced, including national-level legislation prohibiting tobacco sales around schools with the aim of protecting adolescents from earlier smoking initiation. In 2012, another spatial restriction on regulating tobacco retail was implemented by capping the number of new tobacco retail licenses that could be issued within a district.³⁷ However, this capping policy was abolished in 2018.

Therefore, given the lack of work in this area in China, the aim of this paper is to investigate the socio-spatial patterning of tobacco retailing across the city area by examining the spatial disparities of neighbourhood tobacco retail availability as well as the association between tobacco retail availability and neighbourhood deprivation.

4.3 Methods

4.3.1. Study setting

Shanghai is a megacity of China with an administrative area of 6340.5 km² and a population of 24.2 million. The smoking prevalence among adults of Shanghai was 19.7% (2019), but with large disparities between males (37.4%) and females (0.8%).³⁸ The study included all residential communities (akin to a residential neighbourhood) (n = 5,432) with a mean population of 5,888. In the process of rapid urban transformation, due to the historical legacy of the metropolitan city, the level of urban development varied across different areas of Shanghai. The more urbanised areas of the city are characterised by greater economic activity and better access to local infrastructure than the less urbanised areas. Following previous literature in Shanghai,³⁹ the city was stratified by urban centre, urban area, and suburb, which were delineated on the basis of the road network (see Appendix I). Levels of urbanity decreased from urban centre to urban area and to suburb.⁴⁰ The total number of communities classified as urban centre and urban areas were 958 and 1,762, respectively; 2,712 communities outside the Outer Ring Road were classified as suburb.

4.3.2. Tobacco retailer data

Data on tobacco retailers were acquired by web-scraping Points of Interest (POIs) from Baidu Map, which is the biggest online map server in China. As a large and comprehensive collection,⁴¹ POIs have been used in previous research including work on amenities such as retailers.⁴² POIs cover three items of information including name, type, and coordinates. The process of web-scraping is based on keyword searching. Keywords including “convenience store”, “supermarket”, and “tobacco and alcohol outlet” were used to identify the three major types of tobacco retailers in the assessment of neighbourhood-level exposure of tobacco retailing. Through “Ospider” (<https://github.com/skytruine/OSpider>), a total number of 106,889 POIs with duplications were acquired in May 2019.

The process of data validation and cleaning was completed in four steps (Appendix II). In Step 1, duplicates were removed, leaving a total of 20,126 POIs for further cleaning. The data were validated through daytime fieldwork in August 2019. Specifically, 470 POIs across the city were randomly sampled, located, and observed on foot. Through field validation, the following features could be applied to identify tobacco retailers in the online street view of Baidu Map for further validation in step 2: 1) an operating retailer may display a symbol of China National Tobacco Corporation (CNTC), and/or display products/advertisements inside or outside the retailer; 2) for convenience store and supermarket chains, one retailer may be confirmed as a tobacco retailer if any other chain store has been identified as a tobacco retailer (except for chain stores run by wholly foreign-owned enterprises); 3) all tobacco-only outlets were tobacco sellers.

In step 2, based on the features of an operating tobacco retailer, all POIs were verified through searching the images in the online street view of Baidu Map collected before 2019 using the name and address. A total of 19,362 POIs were retained as verified tobacco retailers after removing 4970 out of 25,126 POIs that were identified as not selling tobacco or had closed. A further 794 POIs could not be verified directly due to the coverage in street view, which required further validation. In step 3, further validation was performed to examine the unverified 794 POIs through the published official records of Shanghai TMB which contained information on 4,652 legitimate tobacco retailers in 2014-2018. Through manual examination, 51 out of 794 POIs that were consistent with the official records could be confirmed as operating tobacco retailers. Finally, the invalidated POIs ($n = 743$, 3.69%) were excluded from the subsequent analysis, leaving a total of 19,413 verified tobacco retailers across Shanghai. By 3-level urban classification, 2,680 tobacco retailers were distributed in the urban centre while the total number of tobacco retailers was 5,280 and 11,453 in the urban area and the suburb, respectively. The types of tobacco retailers retained for analyses were: 1) convenience stores (including convenience store chains, groceries or corner shops, gas stations, $n = 9,436$); 2) supermarkets ($n = 6,319$); and 3) tobacco-only outlets (including tobacco-only outlets and liquor stores that sell tobacco products, $n = 3,658$). Considering that the marketing strategies and purchasing patterns of smokers may vary by different retailer types, only the three major types of tobacco retailers were retained for subsequent analyses.

4.3.3 Neighbourhood deprivation

Following previous studies in China,^{43, 44} four neighbourhood-level indicators, including unemployment rate (unemployed residents), low-skilled workers rate (residents who were blue-collar or pink-collar workers), low-educational attainment rate (residents with junior high school education or below), and non-home ownership rate (residents who are tenants), were extracted from the 2010 national census of China at the residential community-level (the smallest administrative division in urban China) and combined to create a single deprivation measure. The four census-based indicators were standardised using z-scores. Consistent with international indices such as the Carstairs and Townsend indices in the UK, all indicators were weighted equally and summed; a higher score indicates a higher level of neighbourhood deprivation (see Appendix III).^{45, 46} Further, for comparison between studies and for better interpreting the findings, all neighbourhoods were grouped into quintiles of deprivation (Q1 = least deprived, Q5 = most deprived). Stratifying neighbourhood deprivation quintiles by urbanity level, the suburb had a greater proportion of the more deprived neighbourhoods (Q3 - Q5), whereas the urban areas were found to have a greater proportion of less deprived neighbourhoods (Q1 - Q2) (see Appendix IV).

4.3.4 GIS spatial analysis

First, using ESRI ArcGIS 10.7.1 Geographic Information System (GIS), all validated tobacco retailers ($n = 19,413$) were mapped based on the coordinates of POIs within 5,432 communities. Kernel density estimation (KDE) was selected to assess geographical availability because it transforms outlet locations into a continuous surface (across Shanghai) that is unconstrained by administrative boundaries. Thus, following methods used previously, the city of Shanghai was separated into 100×100 m grids, and the number and proximity of tobacco retailers with a radius of 800 m (a plausible 10-min walking distance) were calculated.^{15, 24} An advantage of the KDE method is that it places greater weight on tobacco retailers near the centre of the search window (the kernel) and less weight on tobacco retailers that are further away.¹⁵ The KDE value represents the smoothed density of tobacco retailers within the city of Shanghai (Appendix V).

The kernel density values for all tobacco retailers and each type of tobacco retailer were calculated and extracted to the centroids of their subcommunities. The total population of each subcommunity was acquired through the 2010 Chinese census of Shanghai. Neighbourhood tobacco retail availability, defined by the density of tobacco retailers within a given neighbourhood, was represented using the population-weighted KDE of all tobacco retailers for all centroids of subcommunities within each residential community:

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

Where for each residential community i , KDE_i is the population-weighted KDE value, 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 . The tobacco retail availability within neighbourhoods presents a proximity estimate of the density of tobacco retailers (retailers per km²). Further, the distribution of population-weighted KDE values was tabulated and plotted to examine the distribution of neighbourhood tobacco retail availability across the city and by 3-level urbanity.

4.3.5 Statistical analyses

Descriptive statistics were used to characterise the spatial distribution of tobacco retail availability across the city of Shanghai by different types of tobacco retailers. Because of the non-normal distribution of the neighbourhood tobacco retail availability (skewness ranged from 0.49-2.64; kurtosis ranged from 2.97-10.28), median values were used to summarise the results. For each type of tobacco retailer, the median tobacco retail availability was summarised across quintiles of neighbourhood deprivation. The Kruskal-Wallis test, a non-parametric rank-based test (equivalent to a parametric one-way ANOVA), was performed to examine whether tobacco retail availability differed by neighbourhood deprivation quintiles statistically. Furthermore, the effect size was determined using epsilon squared to measure the strength of association between neighbourhood deprivation quintiles and availability of tobacco retailers.⁴⁷ The value of epsilon squared ranges from 0 (no relationship) to 1 (perfect

relationship).⁴⁷ All analyses were stratified by the 3-level urbanity of the city to examine the spatial disparities.

All statistical analyses were conducted using the R packages “Tidyverse” and “Rcompanion”. “GGplot2” was used for plotting the results of descriptive statistics. ESRI ArcGIS 10.7.1 Geographic Information System (GIS) was used for spatial analyses.

4.4 Results

4.4.1. Spatial distribution of tobacco retail availability

The overall median tobacco retail availability for all tobacco retailers was 9.50 tobacco retailers per km² per neighbourhood (95%CI 9.13-9.87). Decreasing with levels of urbanity, the availability was highest in neighbourhoods classified as “urban centre” (20.18 95%CI 19.62-20.94) and lowest in “suburb” neighbourhoods (3.10 95%CI 2.87-3.40) (Table 4.1).

Table 4.1 Distribution of population-weighted KDE of tobacco retailers

Median population-weighted KDE of neighbourhoods (95% CI)				
Retailer type	Urban centre	Urban area	Suburb	Overall
All	20.18 (19.62, 20.94)	12.69 (12.20, 12.96)	3.10 (2.87, 3.40)	9.50 (9.13, 9.87)
Convenience store	10.86 (10.57, 11.38)	5.69 (5.48, 5.89)	1.20 (1.11, 1.33)	4.18 (3.96, 4.42)
Supermarket	3.51 (3.35, 3.66)	3.14 (3.04, 3.24)	1.13 (1.05, 1.22)	2.37 (2.28, 2.46)
Tobacco-only outlets	4.98 (4.69, 5.33)	2.85 (2.66, 3.00)	0.15 (0.11, 0.22)	1.65 (1.53, 1.74)

4.4.2 Neighbourhood deprivation and tobacco retail availability

Stratifying the median tobacco retail availability by neighbourhood deprivation demonstrated the profile was non-linear; with the availability rising from the least deprived quintile (Q1), peaking in the less deprived quintile (Q2) and then dropping to a very low level (Figure 4.1) in quintile 5 (most deprived).

The association between neighbourhood deprivation and median tobacco retail availability varied across urban centre, urban area and suburb neighbourhoods (Figure 4.2). In urban centre neighbourhoods, there is a broadly linear increase from 15.67 to 31.29 in the median availability between Q1 and Q5. The availability peaked in Q3 in urban area, while it peaked in Q2 in suburb. The lowest median availability was found in Q5 for neighbourhoods characterised as urban area, whereas for suburb neighbourhoods, the lowest availability was found in Q3 with a slight increase in Q3-Q5 from 0.85 to 2.56.

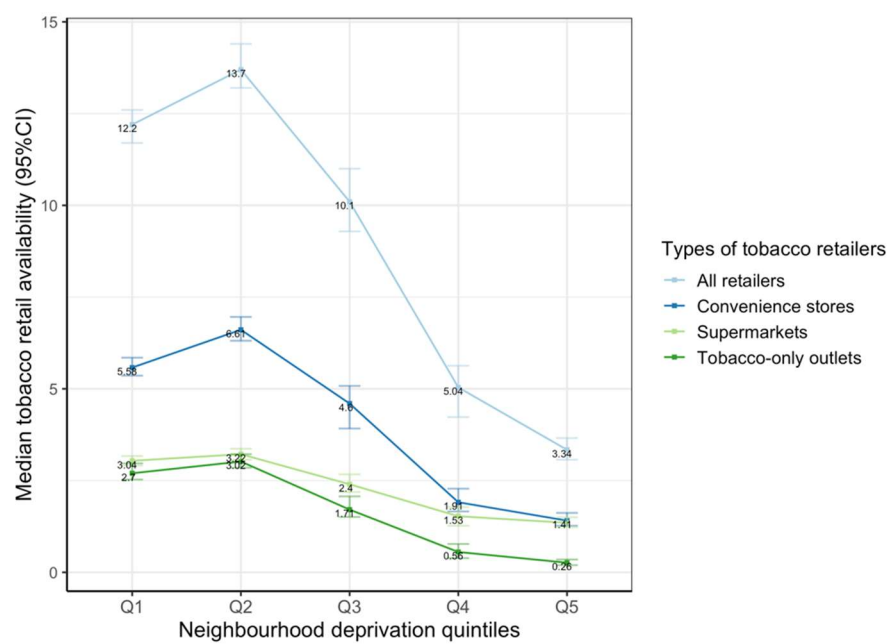


Figure 4.1 The overall association between neighbourhood deprivation quintiles and tobacco retail availability

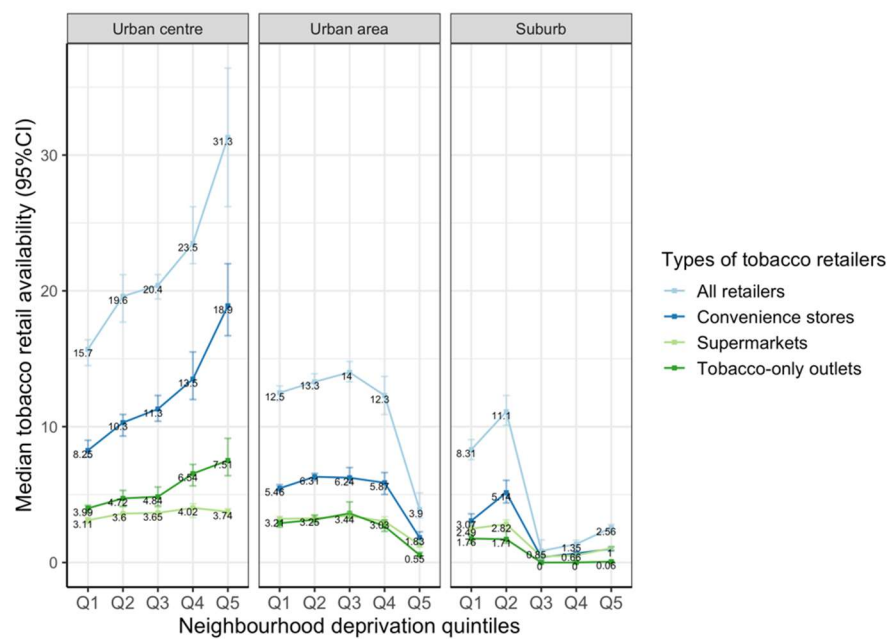


Figure 4.2 The association between neighbourhood deprivation quintiles and tobacco retail availability by 3-level urban classification

Table 4.2 Median population-weighted KDE by types of tobacco retailers and neighbourhood deprivation quintiles by across the city, urban centre and suburb

	Neighbourhood deprivation quintiles					Kruskal-Wallis chi-squared	Effect size (ϵ^2)
	Q1 (Least deprived)	Q2	Q3	Q4	Q5 (Most deprived)		
Across the city							
All retailers	12.19	13.67	10.15	5.04	3.34	611.81	0.11
Convenience store	5.58	6.61	4.60	1.91	1.41	542.55	0.10
Supermarket	3.04	3.22	2.40	1.53	1.35	457.77	0.08
Tobacco-only outlet	2.70	3.02	1.71	0.55	0.26	668.61	0.12
Urban centre							
All retailers	15.67	19.61	20.38	23.53	31.29	168.79	0.18
Convenience store	8.25	10.30	11.32	13.48	18.86	192.25	0.20
Supermarket	3.11	3.60	3.65	4.02	3.74	23.43	0.02
Tobacco-only outlet	3.99	4.72	4.84	6.54	7.51	102.59	0.11
Urban area							
All retailers	12.51	13.26	13.98	12.33	3.90	182.00	0.10
Convenience store	5.46	6.31	6.24	5.87	1.83	153.98	0.09
Supermarket	3.21	3.25	3.44	3.03	1.30	116.33	0.07
Tobacco-only outlet	2.89	3.15	3.62	2.67	0.55	175.90	0.10
Suburb							
All retailers	8.31	11.14	0.85	1.35	2.56	395.21	0.15
Convenience store	3.07	5.14	0.38	0.66	1.00	337.18	0.12
Supermarket	2.49	2.82	0.44	0.52	1.06	255.13	0.09
Tobacco-only outlet	1.76	1.71	0.00	0.00	0.06	387.73	0.14
All p-values < 0.001							

The tobacco retail availability of all tobacco retailers statistically differed by neighbourhood deprivation quintiles ($p < 0.001$) (Table 4.2). Measured by epsilon squared, the effect size of neighbourhood deprivation quintiles on availability varied by 3-level urban classification. The association between neighbourhood deprivation quintiles and availability of all tobacco retailers was strongest in urban centre neighbourhoods ($\epsilon^2 = 0.18$), while the association was weaker in urban area neighbourhoods ($\epsilon^2 = 0.10$) than in suburb neighbourhoods ($\epsilon^2 = 0.15$).

4.4.3 Socio-spatial disparities by tobacco retailer type

In the final stage of the analyses, neighbourhood tobacco retail availability measures were calculated for each retailer type.

In Table 4.1, among the three types of tobacco retailers, the highest availability was found for convenience stores (4.18 95%CI 3.96-4.42) compared to supermarkets (2.37 95%CI 2.28-2.46) and tobacco-only outlets (1.65 95%CI 1.53-1.74). Across the 3-level urbanity, compared to tobacco-only outlets, the availability of supermarkets was greater in urban areas (3.14 95%CI 3.04-3.24) and suburb neighbourhoods (1.13

95%CI 1.05-1.22). Within the urban centre, the availability of convenience stores (10.86 95%CI 10.57-11.38) was 3 times as high as that of supermarkets (3.51 95%CI 3.35-3.66).

The association between neighbourhood deprivation and tobacco retail availability by types of tobacco retailers are presented in Table 4.2. The findings were broadly consistent with the pattern of overall availability, with the highest availability in less deprived neighbourhoods and the lowest availability in the most deprived neighbourhoods. The results also show that, among three retailer types, the availability of convenience stores was highest across all levels of neighbourhood deprivation and the lowest for tobacco-only outlets. On the other hand, the association between neighbourhood deprivation and the availability of tobacco-only outlets was stronger ($\epsilon^2 = 0.12$) than that of convenience stores ($\epsilon^2 = 0.10$) and supermarkets ($\epsilon^2 = 0.08$).

Stratifying the results by urban classification showed that the availability of each retailer type across the three levels of urbanity was consistent with the overall trend, except for the availability of tobacco retail in supermarkets within urban centre neighbourhoods, where there was a slight decrease in Q5. The availability of tobacco-only outlets had the strongest association with urban area neighbourhoods ($\epsilon^2 = 0.10$) and suburb neighbourhoods ($\epsilon^2 = 0.14$). However, in urban centre neighbourhoods, the availability of convenience stores was more strongly associated with neighbourhood deprivation ($\epsilon^2 = 0.20$) than supermarkets ($\epsilon^2 = 0.02$) and tobacco-only outlets ($\epsilon^2 = 0.11$).

4.5 Discussion

4.5.1 Summary of findings

This study examined the socio-spatial patterning of tobacco retailers across Shanghai, China using cross-sectional web-based POIs and census data. As anticipated, the availability of tobacco retailers decreased from neighbourhoods characterised as urban centre to urban area to suburb. Further, there was a non-linear association between neighbourhood deprivation quintiles and tobacco retail availability, which varied by levels of urbanity. Among the three major types of tobacco retailers, convenience stores were the most frequent type of tobacco retailers while the availability of tobacco-only outlets was more associated with neighbourhood deprivation quintiles.

4.5.2 Interpretations of key findings

The significant negative association between neighbourhood deprivation and tobacco retail availability is inconsistent with previous findings in HIC countries, where tobacco retailers tend to be more available in more deprived neighbourhoods.^{20, 21, 23} In contrast, in Shanghai, the most deprived neighbourhoods had the lowest availability of tobacco retailers, suggesting that residents of the most deprived neighbourhoods are disadvantaged in their access to a range of basic resources, including various types of retailers.²⁴ In addition, the lowest availability of tobacco retailing in the most deprived neighbourhoods may be partly a consequence of low purchasing power among residents of these areas,²⁴ which is consistent with the previous evidence in China suggesting that lower-income households spend less on tobacco products;⁴⁸ smokers from the most deprived neighbourhoods of Shanghai may purchase cheaper cigarettes from fewer retailers.

The finding that the highest availability of tobacco retailers was in the urban centre is broadly consistent with work in North America^{19, 21} and Scotland.^{15, 24} Uneven urban economic development across Shanghai is a possible explanation for this patterning. Similar to all types of retailing, tobacco retailers tend to concentrate in the urban centre. The retail market in suburban neighbourhoods, which has seen a transformation from an agrarian to an industrialised economy in recent years, is still under development.

By contrast, the retail market in the urban centre of Shanghai is well-established and highly networked, with more commercial activity. Uneven consumer demand across the city may also help to explain the geographical differences in tobacco retailing, with more demand (i.e. more smokers) in parts of the city with a greater population density.²⁷ In Shanghai, the population density in the urban centre was five times that in the suburb (see Appendix VI). From the perspective of policymaking, the findings could also be attributed to the activities of the local TMB,²⁸ who issue licenses, oversee tobacco control in the city, and at the same time promote tobacco sales at the local level.^{28, 34} In the former zoning regulation regarding tobacco retail in Shanghai (2012), to meet consumer demand, TMB permits higher caps on the thresholds for newly issued tobacco retail licenses in areas with more economic activity (i.e. more urbanised areas).³⁷ The dual roles of TMB may intensify the geographical differences in tobacco retail availability.

The study findings also demonstrated that the relationship between tobacco retail availability and neighbourhood deprivation varied across urban centre, urban area and suburb. In urban centre neighbourhoods, similar to findings from HICs,²¹⁻²³ greater availability was found in more deprived neighbourhoods. However, in suburban neighbourhoods, there was a non-linear association between deprivation and the availability of tobacco retailing with the highest availability in deprivation quintile 2, and the lowest in quintile 3. It is feasible that this finding may be specific to large cities such as Shanghai whereby there is an ongoing transition in the suburban tobacco retail market driven by the rural-to-urban transformation in the suburbs.

The local TMB/tobacco industry may play an important role in the socio-spatial patterning of tobacco retail by different retailer types by preferring convenience store chains and tobacco-only outlets over other retailer types when issuing tobacco retail licenses. The convenience store chains provide a unified and established retail network with a widespread availability of point of sales across the city, which could benefit the development of a more efficient tobacco retail network,⁴⁹ further ensuring the ubiquity and easy access to tobacco products. Most of the tobacco-only outlets are run by local TMB/tobacco corporations, which advantages tobacco-only outlets in terms of tobacco sales, promotion, and marketing.⁴⁹ Further, albeit the trend remained non-linear, our

study found the availability of tobacco-only outlets was more sensitive to the effect of neighbourhood deprivation in contrast to convenience stores and supermarkets, which may be because the tobacco-only outlets seek to maximise profits by targeting consumers from less deprived backgrounds with better purchasing power. The finding emphasises the conflicting roles of local TMB, suggesting an urgent need for a greater separation between tobacco control policymaking and the tobacco industry.

4.5.3 Limitations

The study has limitations. First, due to the lack of a comprehensive tobacco retailer register, the completeness of POIs regarding tobacco retailers cannot be assessed formally. Further, the POIs data does not include information regarding the size of tobacco retailers, the volume of sales, and the sub-types of major tobacco retailer types, which could be used to better characterise tobacco retail availability across the city. Further, since illicit tobacco retailers were not identifiable from the POI database, our study was restricted to legitimate tobacco retailers. Unlike earlier work,⁵⁰ our study also did not include tobacco “kiosks”. However, the number of kiosks across the cities of China has decreased dramatically since 2012,⁵¹ and by 2019, the number of kiosks in Shanghai was estimated to be fewer than 300.⁵² Although the Shanghai TMB hold data on all legitimate tobacco retailers across Shanghai, the data are not available to researchers. Therefore, POIs provide the most comprehensive open-source data relating to tobacco retailing. Second, the study relies on cross-sectional data where measurements, including the tobacco retail availability index constructed by POIs and the census-based neighbourhood deprivation index that were constructed at different time points using the most recently available data (2019 and 2010 respectively). However, between 2010 and 2019, a large amount of cultivated land around the urban periphery of Shanghai has been developed for residential and commercial purposes. These areas may have experienced socioeconomic changes that were not considered. Finally, this research focuses on socio-spatial patterning of exposure to tobacco retail and does not consider impacts on smoking (e.g. smoking rates, daily smoking) or health outcomes. Further research in China linking geospatial tobacco retail to smoking behaviour data is urgently needed to investigate the relationship between neighbourhood deprivation, tobacco retail availability, and individual-level smoking.

4.6 Conclusion

The findings in this paper suggest that in Shanghai there was a greater availability of tobacco retailing in more urbanised areas and medium-deprived neighbourhoods, with convenience stores being the most common type of tobacco retailer across the city. Examining the socio-spatial patterning of tobacco retail could provide crucial evidence for further tobacco control policies in Shanghai and other megacities of China.

As a signatory of the WHO Framework Convention on Tobacco Control (FCTC), China has made some progress in the development of tobacco control initiatives, particularly over the past six years, including smoke-free ordinances, cessation support, health warnings on tobacco products, and a ban on tobacco advertising and sponsorship.³ However, there is still a long way to go for tobacco control in China, not least the full implementation of the WHO FCTC, and to achieve the ambitious goals of reducing smoking prevalence and health inequality detailed in Healthy China 2030,⁵³ a broad range of additional measures need to be considered. These measures require a comprehensive tobacco control strategy, including addressing the ubiquitous local availability of tobacco products in China.

From the perspective of reducing socioeconomic inequalities in smoking and improving the effectiveness of tobacco control strategies, this study emphasises the need for greater efforts in regulating tobacco retailing at the neighbourhood level. In addition to reducing the overall availability of tobacco retailers, policymakers should consider the possibility of implementing neighbourhood-level spatial restrictions on different types of tobacco retailers, for example, through changes to the tobacco retail licensing process. Policy interventions in this area should also be cognizant of the significant socio-spatial disparities between different types of tobacco retailers as well as the advertising, promoting, and marketing activities among different types of tobacco retailers.⁵⁴ Our study provides important evidence that place-based spatial restrictions that aim at reducing neighbourhood-level tobacco exposure should form a key part of further policy interventions to address the social and geographical differences in smoking.

4.7 References

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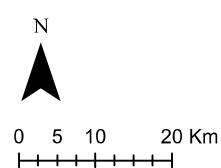
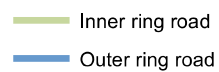
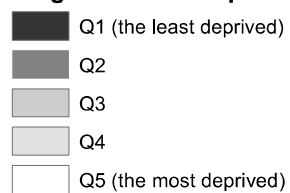
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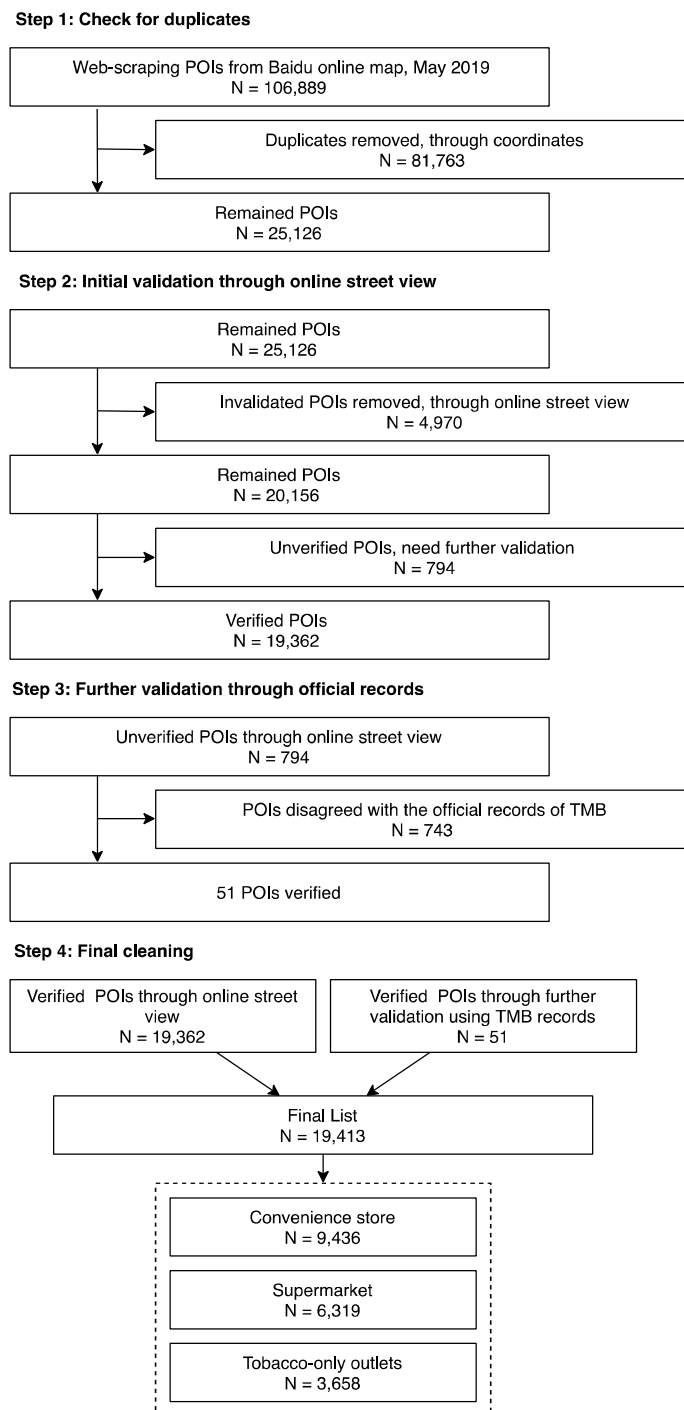
4.8 Supplementary Materials

Appendix I. 3-level urban classification of Shanghai

Neighbourhood deprivation quintiles



Appendix II. Workflow of tobacco retailer data validation and cleaning



Appendix III. Descriptive statistics of deprivation index based on the 6th census of China using equal-weighting approach

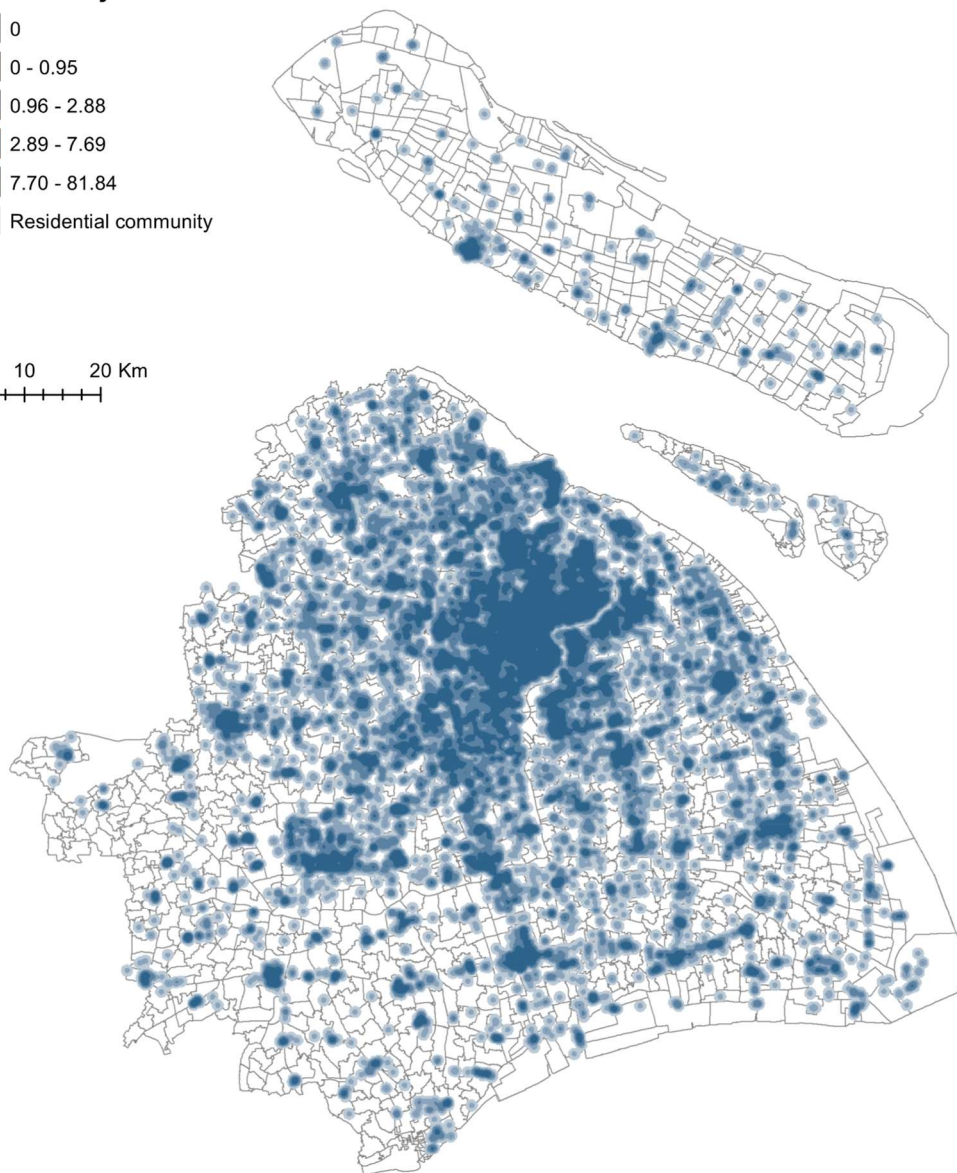
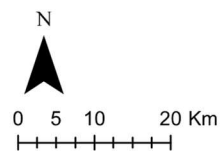
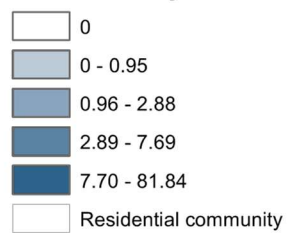
Indicator	Definition	Mean (SD)%			
		Urban centre	Urban area	Suburb	Overall
Unemployment rate (%)	Percentage of unemployed residents.	9.96 (5.18)	9.68 (5.90)	4.48 (4.88)	7.13 (5.91)
Low-skilled workers rate (%)	Proportion of residents who are blue-collar worker and pink-collar worker.	23.80 (10.44)	26.22 (14.10)	46.17 (16.99)	35.75 (18.35)
Education of junior school or below (%)	Proportion of residents with education of junior school or below.	38.41 (13.25)	41.41 (15.08)	67.29 (18.48)	53.80 (21.39)
Non-homeownership (%)	Proportion of residents who are tenants.	44.75 (28.32)	29.49 (21.06)	36.80 (27.21)	35.83 (26.12)

Appendix IV. Distribution of neighbourhood deprivation quintiles, N(%)

No. of residential communities (%)					
Urban classification	Q1	Q2	Q3	Q4	Q5
Urban centre	277 (25.48)	203 (18.69)	174 (16.01)	146 (13.44)	158 (14.55)
Urban area	533 (49.03)	515 (47.42)	333 (30.63)	220 (20.26)	161 (14.83)
Suburb	277 (25.48)	368 (33.89)	580 (53.36)	720 (66.30)	767 (70.63)
Overall	1087 (100.00)	1086 (100.00)	1087 (100.00)	1086 (100.00)	1086 (100.00)

Appendix V. Kernel density estimation of tobacco retailers in ArcGIS 10.7.1

Kernel Density Estimation of Tobacco Retailers



Appendix VI. Spatial distribution of neighbourhood population count, population density, count of subcommunities by means

	Population count (SD)	Population Density (SD) (per km ²)	No. of subcommunities within neighbourhoods (SD)
Overall	5888.17 (5020.95)	23406.12 (23773.40)	15.37 (9.76)
Urban centre	4539.27 (2029.80)	45972.97 (27563.41)	12.77 (6.11)
Urban area	5969.74 (4216.86)	33710.08 (20232.88)	16.29 (9.28)
Suburb	6311.67 (6055.72)	8739.97 (11574.69)	15.69 (10.90)

Appendix VII. Definitions on retailer types, count (%) of tobacco retailers by types

Retailer type	Definitions	N (%)
Convenience store	Convenience store chains, corner shops, gas stations, groceries	9,436 (48.61)
Supermarket	Mega, small and medium supermarket (chains)	6,319 (32.55)
Tobacco-only outlet	Tobacco specialty, liquor store that selling tobacco products	3,658 (18.84)
Overall	--	19,413 (100)

Appendix VIII. A justification on why using quintiles rather than a continuous measure

The reason why quintiles were chosen for grouping deprivation index is two-fold:

- 1) Firstly, compared to a continuous measure, the findings based on levels of deprivation are easier to present graphically and more straightforward to be interpreted, especially for interpreting the implications for policymaking.
- 2) Secondly, when compared to a continuous measure, the equal-sized groups are more reproducible, allowing for comparison and confirmation between studies. Quintiles are further preferred over other types of quintiles as it has been widely used in health and economic statistics, for example, the grouping of deprivation indices normally uses quintiles rather than quartiles or tertiles.

The grouping of the deprivation index does not affect the nature of the socio-spatial patterning of tobacco retail availability. Relatively, quintiles enabled providing more detailed information than quartiles and were easier to be interpreted as compared to a continuous measure. The distribution of tobacco retail availability by a continuous measure and by other groupings of quantiles was provided as follows:

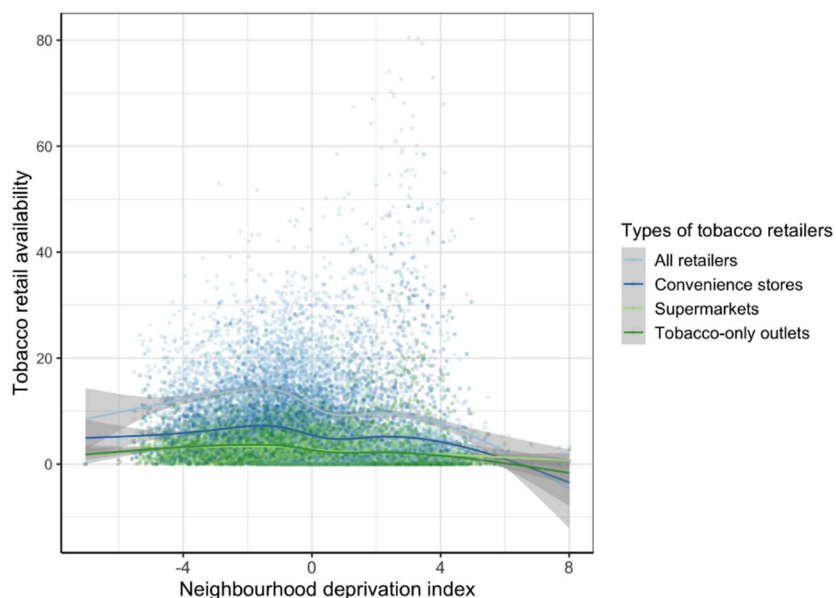


Figure 1a. The overall distribution of tobacco retail availability by neighbourhood deprivation index (continuous measure)

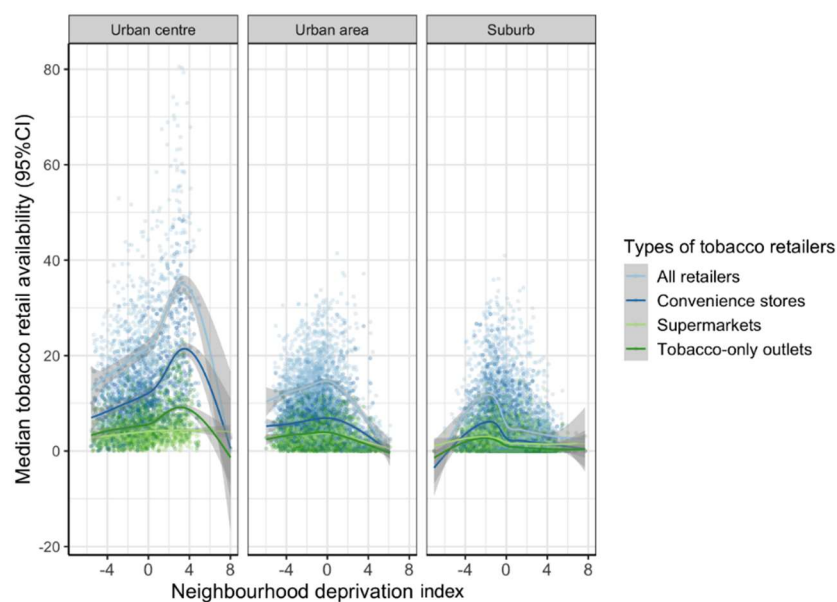


Figure 1b. The stratified distribution of tobacco retail availability by neighbourhood deprivation index (continuous measure) in urban centre, urban area and suburb neighbourhoods.

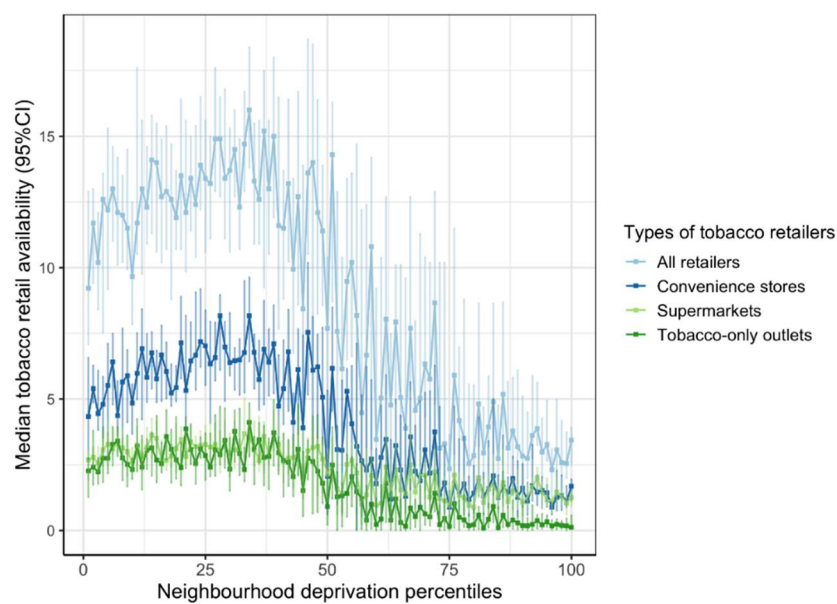


Fig 2a. The overall distribution of tobacco retail availability by neighbourhood deprivation percentiles

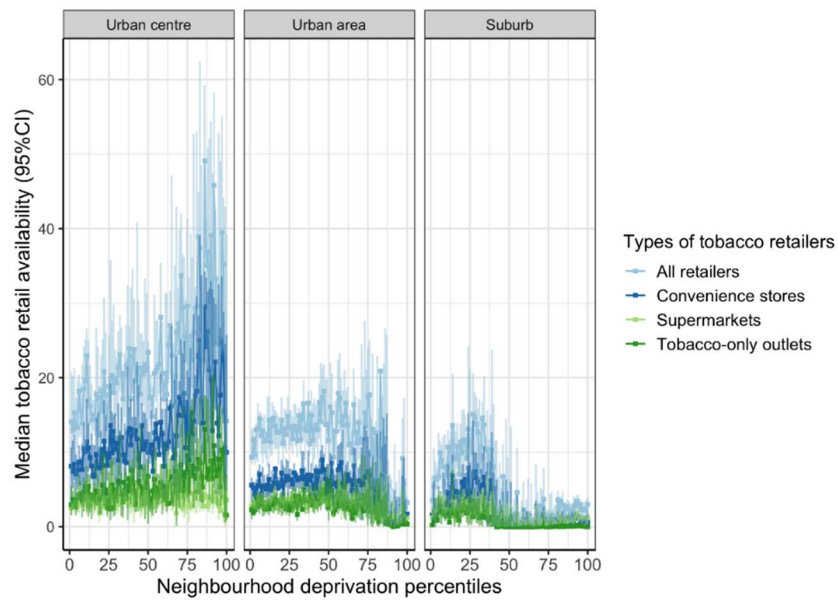


Fig 2b. The stratified distribution of tobacco retail availability by neighbourhood deprivation percentiles

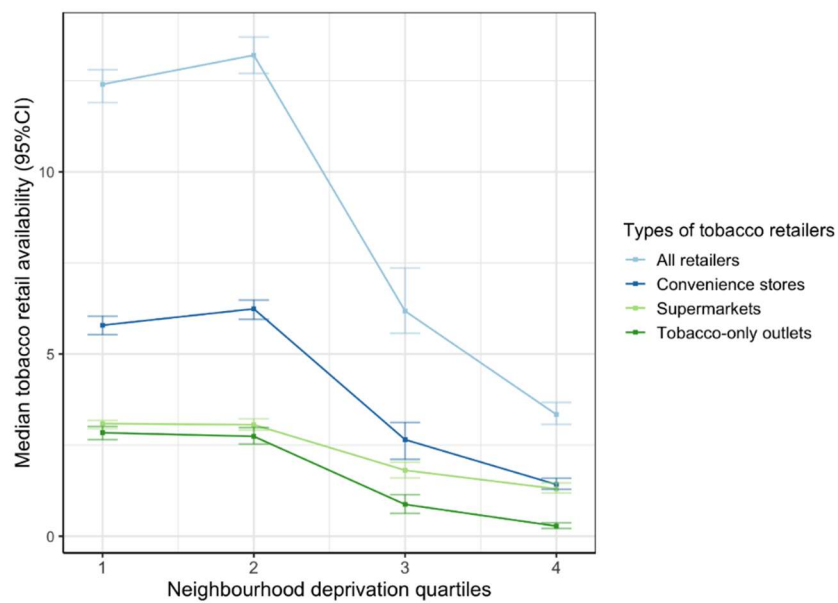


Fig 3a. The overall distribution of tobacco retail availability by neighbourhood deprivation quartiles

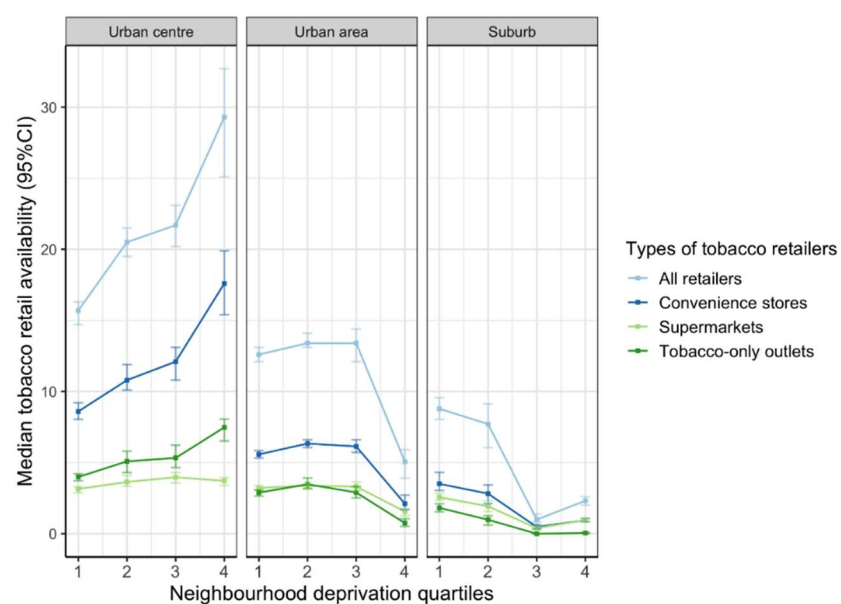


Fig 3b. The stratified distribution of tobacco retail availability by neighbourhood deprivation quartiles

Chapter 5 A spatial analysis of the tobacco retail environment around public schools in Shanghai, China

5.1 Abstract

Background. In China, 12.9% of adolescents aged 13-15 experimented with smoking (2019). Greater access to tobacco retail has been identified as a major cause of earlier smoking initiation among this age group. This study examined the distribution of tobacco retailers around public schools in Shanghai, China, determining whether retailers clustered around schools, and the level of compliance with the spatial restrictions prohibiting tobacco retail within 50 m of school areas.

Methods. Tobacco retailers ($n = 19,413$) were extracted from the web-based Points of Interest database in 2019. Using GIS analysis, across Shanghai, the distribution of tobacco retailers around public schools ($n = 1,483$) was calculated using the number and proportion of tobacco retailers within 400 m and 800 m distances to the main entrance based on the road network. The degrees of clustering of tobacco retailers within 400 m and 800 m of public schools were determined using K-function analysis. Compliance with the spatial restriction was examined by calculating the proportion of public schools with at least one tobacco retailer within 50 m of distance. Stratified analyses considered types of schools, levels of urbanity, school deprivation, and types of tobacco retailers.

Results. Overall, 79.2% and 95.8% of public schools in Shanghai were within 400 m and 800 m (respectively) of a tobacco retailer. In addition, 29.4% and 60.1% of tobacco retailers were allocated within 400 m buffers and 800 m buffers around the main entrance, respectively. Specifically, a median of 3 tobacco retailers fell within 400 m buffers, while 15 tobacco retailers fell within 800 m buffers, with about 5.9% of public schools being exposed to non-compliant tobacco retailers. Furthermore, there is evidence that tobacco retailers were significantly clustered around public schools within 400 m and 800 m. Additionally, the distribution, the clustering pattern, and the non-compliant tobacco retailers around public schools in Shanghai differed by levels of urbanity and types of tobacco retailers.

Conclusion. The exposure to tobacco retailers within walking distance of public schools in Shanghai was high, particularly in more urbanised areas. The current spatial restriction on tobacco retail around public school areas is proving insufficient to limit

availability among students. Policymakers should consider a range of strategies to tighten spatial restrictions on tobacco retailing around the school to prevent earlier smoking initiation among students.

5.2 Introduction

Previous research suggests that the age of initiation is significantly related to current frequent smoking and daily smoking.¹ Earlier smoking initiation is found to be linked to a longer duration of smoking, heavier daily consumption, and increased chances of nicotine dependence.¹⁻³ Smokers who started smoking before the age of 19 were 2.4 times more likely to become heavy smokers than those who started smoking after the age of 26.⁴ Preventing earlier smoking initiation is therefore an important priority in tobacco control.

Reducing the retail availability of tobacco has been proposed as a key component of strategies to achieve tobacco “endgames” in many countries.⁵⁻⁷ Licensed tobacco retail density has been identified as a predictor of adolescent lifetime smoking.⁸ Studies in the US and Canada have found that higher densities of tobacco retail around schools tend to be significantly associated with the prevalence of ever smoking among students,^{9,10 11-13} and higher susceptibility to future smoking among non-smokers.^{11 14} Prohibiting tobacco retailers within a certain distance of schools has been shown to reduce retailer density,³ and communities with fewer tobacco retailers near schools have a lower youth smoking rate.¹⁵⁻¹⁷ In addition, compliance with zoning regulations in Mumbai, India was found to be associated with a lower risk of current tobacco use and current smokeless tobacco use among students.¹⁸

Younger and more vulnerable populations are often targeted by the tobacco industry to ensure a steady stream of replacement smokers.^{19, 20} In the US, schools with more students from a low-income or minority background are more likely to be exposed to proximal tobacco retailing.²¹ Moreover, illicit sales of tobacco to students tends to be more common among tobacco retailers located in the vicinity of high schools in majority African-American block groups.^{22,23} Furthermore, tobacco retail density was found to be associated with experimental smoking among students residing in urban areas.⁹

China is the largest producer and consumer of tobacco, with over 300 million adult smokers.²⁴ In China, 22.2% of ever daily smokers started smoking on a daily basis before the age of 18.²⁴ Although China is a signatory of the WHO Framework

Convention on Tobacco Control (WHO FCTC), tobacco control interventions remain limited,²⁵ with a particularly urgent need for additional measures aimed at addressing underage smoking. According to the 2019 Global Youth Tobacco Survey of China (GYTS), the prevalence of experimental smoking and the prevalence of daily smoking among adolescents aged 13-15 was, respectively, 12.9% and 3.9%.²⁶ Easy access to tobacco retailers has been identified as one of the contributing factors to the high prevalence of smoking among Chinese youth.^{27,28} Protecting youth from the tobacco retail environment has been identified as a critical approach to reducing smoking rates among adults.²⁸ Regulations in China prohibit the sale of tobacco products to a person under the age of 18.²⁹ Furthermore, although uncommon in high-income countries, there is national-level legislation that restricts tobacco sales near primary and secondary schools in China.²⁹

As one of the most important “child spaces”, the tobacco retail environment around schools in China has seldom been studied, nor has compliance with the spatial restrictions of tobacco retail around schools. In Beijing, an average of two tobacco retailers were allocated around schools.³⁰ In Changsha, there were an average of three tobacco retailers in the vicinity of a school, with a higher density of tobacco retailers within 0-100 m of the school than 100-200 m.²⁸ In Hangzhou, nearly half of the schools were in the vicinity of a tobacco retailer, with an average distance from a school to the closest tobacco retailer of 67.7 m.³¹ Unlike the findings in Changsha, there were no significant differences in the distribution of tobacco retailers within 0-100 m of the school compared to those outside 100m of the school.³¹ A more recent study examined 1512 tobacco retailers surrounding 904 schools across 10 Chinese cities, including Shanghai, suggesting that 53.1% of schools in Shanghai were in the vicinity of a tobacco retailer at a distance of 100 m.³² However, all prior Chinese studies used random sampling approaches, which may result in potentially biased study samples, especially in the context of megacities where the sociospatial disparities are significant within metropolitan areas. Notably, some of these studies measured the distribution of tobacco retailers using the count of tobacco retailers through Euclidian (straight line) distance, which neglects the complexity of the road network. Furthermore, the socio-spatial factors associated with schools have not been examined in relation to the distribution of tobacco retailers around school areas. Another study in Changsha used

K-function to identify the clustered pattern of tobacco retailers, but the work was limited to unlicensed tobacco retailers and only examined the pairwise association between two retailers, rather than the association between tobacco retailers and other urban facilities or amenities, as well as the variation in types of tobacco retailers.³³ In addition, specific spatial restrictions regarding tobacco retail, in particular those restrictions around school environments, have not been investigated.

For the purpose of protecting the underage and enacting effective tobacco control, further understanding of the tobacco retail environment around schools in China is urgently needed. This study addressed this research gap and examined the characteristics of the distribution of tobacco retailers around public schools in Shanghai and considered whether and to what extent tobacco retailers cluster around public schools. Furthermore, the compliance of tobacco retailers with local spatial restrictions on tobacco retail around school areas was examined to evaluate the effectiveness of enforced spatial restrictions.

5.3 Methods

An examination was conducted of the tobacco retail environment around public schools in Shanghai, the biggest mega-city of China, covering an administrative area of 6340.5km² with a population of 24.2 million residing in 16 districts.

5.3.1 Data

5.3.1.1 Tobacco retailer data

Shanghai tobacco retailer data was acquired by web-scraping Points of Interest (POIs) from Baidu, which is one of the biggest online map servers in China, in May 2019. All POIs have been geocoded. Focusing on daily exposure, the web-scraping of POIs used keywords including “convenience stores”, “supermarkets” and “tobacco-only outlets”. All POIs of tobacco retailers were validated through online street view auditing and referencing published data from the Shanghai Tobacco Monopoly Bureau (TMB), leaving a total number of 19,413 tobacco retailers, including 9,436 convenience stores, 6,319 supermarkets, and 3,658 tobacco-only outlets across the city of Shanghai.

5.3.1.2 Public school data

According to the Shanghai Statistical Yearbook (2018), 90% of students aged 6-18 were enrolled in public schools.³⁴ Unlike public schools, private schools enrol students across the city of Shanghai, while public schools accept students only from the district where the schools are located. Therefore, to simplify the process of research, only public schools were considered for further analysis.

Public school data was sourced from the official enrolment plan of public schools in Shanghai (2019).³⁵⁻³⁷ Pro-smoking messages can reach young children and affect their attitudes and behaviours regarding smoking through advertising, point-of-sale displays, promotions, etc.³⁸⁻⁴⁰ Children who were exposed to tobacco advertising, marketing, and promotion might not initiate smoking before age 11, but its influence can be inferred from their tobacco awareness.³⁹ Earlier evidence from low- and middle-income countries, including China, also suggests tobacco advertising and marketing may influence awareness and attitudes towards tobacco products among very young

children,⁴⁰ therefore, all types of public schools, categorised using the range of school years, including primary school (Years 1-5), middle school (Years 6-9), high school (Years 10-12), secondary school (Years 6-12), and 9/12-year school (Years 1-12), were studied. Comprising all campuses of public schools in Shanghai that had an enrolment plan in 2019, a total of 1,483 public schools were geocoded using the address through the API of Baidu Online Map. Considering the spatial restrictions for tobacco retail set by the Shanghai TMB, where tobacco retail is prohibited within a distance of 50 m from the main entrance of schools along the street, all analyses were conducted using the geocoordinates of the main entrance of public schools.

5.3.1.3 School deprivation index

To capture the social characteristics of school environments, considering the imperfect alignment between school catchment area units (i.e. divided by road) and census units (i.e. divided by the residential community), the Huff model was applied to estimate the catchment areas by probabilities as an alternative to the official catchment areas (see Appendix I). Then the school deprivation index was calculated using the neighbourhood deprivation index, which was constructed using the 2010 Chinese census through an equal-weighting approach and further weighted by the school-aged population (aged 5-19) in each residential community within the catchment area (see Appendix II). Then the school deprivation index was grouped into quintiles, from the least deprived (Q1) to the most deprived (Q5).

5.3.2 Analyses

To describe the distribution of tobacco retailers around public schools, using network-based service area analysis, the number of tobacco retailers located within road network buffers around the main entrances of all public schools was calculated using the proportion, median, minimum, and maximum number of tobacco retailers. In line with previous research,⁴¹ distances of 400 m and 800 m were selected to approximate a 5 min and 10 min walking distance, respectively. Further, to examine compliance with spatial restrictions on tobacco retail, the proportion of public schools that have at least one tobacco retailer within the 50 m and 100 m road network buffers was calculated. 50 m was selected because tobacco retail is prohibited within a radius of

50 m from the main entrance of campuses in Shanghai,⁴² while 100 m is the threshold in many other cities of China (e.g. Beijing,⁴³ Hangzhou,⁴⁴ Changsha⁴⁵).

Bivariate and multivariate K-function analyses were applied to identify whether tobacco retailers were clustered around public schools and the extent of any clustering. The utility of the K-function is that it enables examination of the degree of clustering at multiple distances from the main entrance of public schools by providing an estimate of the measure of spatial dependence.⁴⁶ The K-function has been used in a number of previous studies of food environments and urban commercial facilities,⁴⁶⁻⁴⁹ while its utilisation in the tobacco retail environment is limited.³³ The generalized K-function is defined as follows:

$$K_{ij}(r) = \lambda_j^{-1} E[N_r]$$

Where N_r is the expected number of type j events, i.e. convenience store, within a distance r (up to 800m) of a randomly chosen type i event, i.e. public school, and λ is the intensity of the process, measured in events per unit area.^{50,51} Under complete spatial randomness (CSR), the multitype K-function could be simplified to $K_{ij}(r) = \pi r^2$.

Following precedent research,^{46,52} the ratio of the observed K-function curve was divided by the expected K-function curve in order to estimate the clustering at the predefined distance thresholds from the schools. Simulation envelopes based on 99 simulations under the assumption of no spatial dependence were created around the expected K-function to examine the statistical significance of the clustering. All simulation envelopes were tested under the null hypothesis that there was no clustering in the point pattern. Ripley's edge correction was also applied to adjust the K-function for schools located at the edge of the study area.

For all analyses, comparisons were made of types of schools, 3-level urban classification, school deprivation quintiles, and types of tobacco retailers. All statistical analyses were undertaken using Stata 13 IC. Spatial analysis was carried out using ArcGIS 10.7.1 and the R packages "huff-tools"⁵³ and "spatstat".⁵⁴

5.4 Results

Figure 5.1 shows the distribution of tobacco retailers and public schools across Shanghai included in the analysis. Across the city, within a distance of 400 m from the main entrance of public schools, 79.2% of public schools were in the vicinity of at least one tobacco retailer, while this proportion grew to 95.8% as the distance increased to 800 m (see Appendix III).

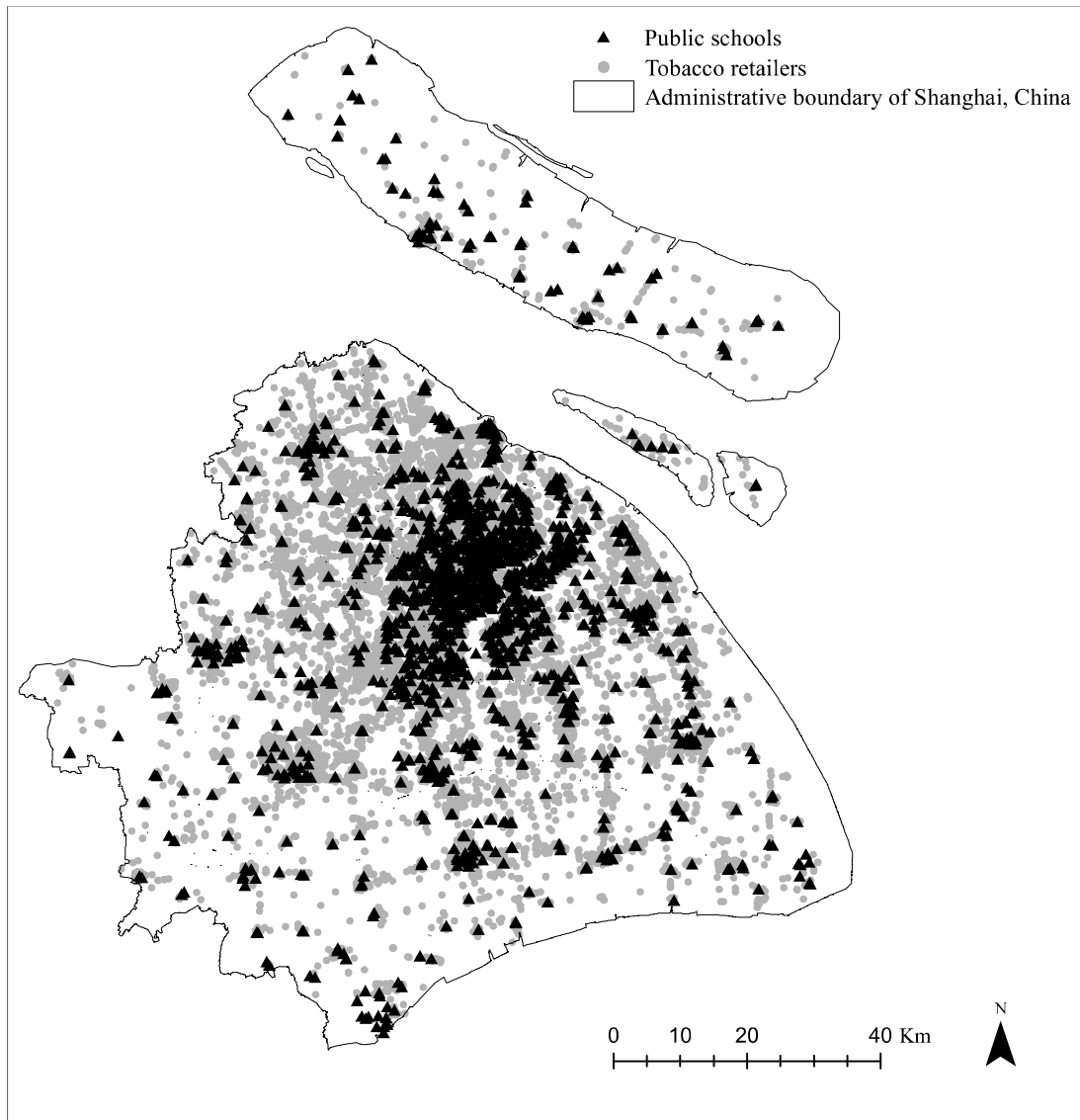


Figure 5.1 Spatial distribution of tobacco retailers and public schools

5.4.1 The distribution of tobacco retailers around all public schools

Table 5.1 presents the number (proportion) of tobacco retailers around the main entrances of public schools across Shanghai. For all types of public schools, 29.4% (n = 5710) of tobacco retailers fell within 400 m-buffers of the main entrance, while it increased to 60.1% (n = 11659) within 800 m-buffers. Among different school types, across distances, primary schools were found with more tobacco retailers (17.6%-45.9%), followed by middle schools (8.5%-25.6%), with the most limited proportion of tobacco retailers found around secondary schools (2.5%-9.2%).

Table 5.1 Number (%) of all tobacco retailers within 400 m and 800 m of schools by types of school, levels of urbanity and deprivation, and types of tobacco retailer

	N (%) within 400 m	N (%) within 800 m
Types of school		
All	5710 (29.4%)	11659 (60.1%)
Primary	3408 (17.6%)	8908 (45.9%)
Middle	1647 (8.5%)	4975 (25.6%)
High	638 (3.3%)	2285 (11.8%)
Secondary	486 (2.5%)	1793 (9.2%)
9/12-year	786 (4.1%)	2469 (12.7%)
Urban classifications		
Urban centre	1477 out of 2680 (55.1%)	2608 out of 2680 (97.3%)
Urban area	1947 out of 5272 (36.9%)	4112 out of 5272 (78.0%)
Suburb	2274 out of 11461 (19.8%)	5141 out of 11461 (44.9%)
School deprivation quintiles		
Q1(Least deprived)	1239 (6.4%)	3123 (16.1%)
Q2	1419 (7.3%)	3548 (18.3%)
Q3	1192 (6.1%)	3294 (17.0%)
Q4	1048 (5.4%)	3094 (15.9%)
Q5(Most deprived)	1367 (7.0%)	3275 (16.9%)
Types of tobacco retailers		
Convenience stores	2862 (30.3%)	5697 (60.3%)
Supermarkets	1480 (23.4%)	3213 (50.8%)
Tobacco-only outlets	1368 (37.4%)	2749 (75.1%)

Further examining the distribution of tobacco retailers by levels of urbanity, quintiles of school deprivation, and types of tobacco retailers, significant differences between groups were only found by levels of urbanity. Across distances, a greater proportion of tobacco retailers fell within 400 m- and 800 m-buffers of public schools in urban centre (55.1%-97.3%), followed by urban area (36.9%-78.0%), and rarer in suburb (19.8%-44.9%). By quintiles of school deprivation, there was a slightly higher proportion in Q2 (7.3%-18.3%) and a relatively lower proportion in Q4 (5.4%-15.9%). For different types of tobacco retailers, a greater proportion was found for tobacco-

only outlets (37.4%-75.1%), followed by convenience stores (30.3%-60.3%) and supermarkets (23.4%-50.8%) within 400 m-buffers.

5.4.2 The distribution of tobacco retailers around each public school

To further characterise the tobacco retail environment around each public school, the median number of tobacco retailers around the main entrances of each public school was described at distances of 400 m and 800 m in Table 5.2. As expected, the total number of tobacco retailers around public schools grew as the buffer radius increased. Within 400 m-buffers, the total number of tobacco retailers surrounding each public school ranged from 0-36 with a median of 3, while it ranged from 0-93 with a median of 15 within 800 m-buffers. Among different types of school, primary school was found with the highest median within 400 m-buffers (4, 0-34), and the highest median was found around secondary school (18.5, 0-93) within 800 m-buffers.

Table 5.2 Median (min, max) of tobacco retailers around the main entrance of each public school by types of schools, levels of urbanity and school deprivation, and types of tobacco retailers

	Distance from the main entrance of public schools			
	400 m		800 m	
	Median	Min, max	Median	Min, max
Types of schools				
All	3	0, 36	15	0, 93
Primary	4	0, 34	17	0, 82
Middle	3	0, 27	14	0, 78
High	3	0, 21	15.5	0, 65
Secondary	3.5	0, 36	18.5	0, 93
9/12-year	2	0, 22	11.5	0, 89
Urban classifications				
Urban centre	6	0, 36	26.5	1, 93
Urban area	3	0, 20	18	0, 51
Suburb	2	0, 19	10	0, 51
School deprivation quintiles				
Q1 (Least deprived)	4	0, 15	19	0, 56
Q2	4	0, 36	21	0, 93
Q3	3	0, 21	14	0, 60
Q4	2	0, 19	10	0, 77
Q5 (Most deprived)	3	0, 34	13	0, 89
Types of tobacco retailers				
Convenience stores	1	0, 22	7	0, 53
Supermarkets	1	0, 7	4	0, 18
Tobacco-only outlets	0	0, 12	3	0, 35

The distribution of tobacco retailers around each public school varied across levels of urbanity. Across radiuses at distances of 400 m and 800 m, the median number of tobacco retailers decreased from 6-26.5 (urban centre), to 3-18 (urban area), and to 2-10 (suburb). The distribution by school deprivation quintiles showed no significant differences, with the largest median number of tobacco retailers in Q2 (4–21) and the smallest median in Q4 (2–10). Among retailer types, more convenience stores were found around each public school, with a median of 1 (0-22) in 400 m-buffers and a median of 7 (0-53) in 800 m-buffers, which were followed by supermarkets (1-4) and tobacco-only outlets (0-3).

5.4.3 Spatial clustering of tobacco retailers around public schools

To examine whether there was any clustering of tobacco retailers around public schools, a ratio was derived by dividing the observed K-function curve by the expected K-function curve. A ratio close to 1 indicates no statistical evidence of clustering, whereas a ratio greater than 1 indicates evidence of clustering. Table 5.3 indicates that tobacco retailers were significantly clustered around all public schools in Shanghai at distances of 400 m (12.30) and 800 m (10.36). The ratios were similar among all types of schools. At a distance of 400m, the ratio for high schools was the greatest (12.91), followed by primary schools (12.80). However, the higher degree of spatial clustering of tobacco retailers was found around secondary schools (12.34) at a distance of 800 m, followed by high schools (11.08). Across all distances, the lowest degree of spatial clustering was found around 9/12-year schools (10.36-8.65).

Examining spatial clustering by urbanity level, at distances of 400 m and 800 m, the degree of spatial clustering of tobacco retailers increased from urban centre (2.06-1.80), to urban area (3.07-2.74), and to suburb (15.94-11.87), which is contrary to the pattern of distribution described by number (%). Across school deprivation levels, tobacco retailers tended to be more clustered around public schools in Q2 (15.34-13.64), while tobacco retailers were less clustered around public schools in Q4 (9.72-8.06). For the clustering pattern of different types of tobacco retailers, at distances of 400 m and 800 m, tobacco-only outlets were the most clustered type around public schools (15.33-13.22), followed by convenience stores (12.91-10.88). Supermarkets were the least clustered type among the three major types of tobacco retailers (9.58-8.06).

Table 5.3 Ratios of K-function from the main entrance of public schools

	Distance from the main entrance of public schools			
	400 m		800 m	
	Ratio	(95% CI)	Ratio	(95% CI)
Types of schools				
All	12.30	(11.49, 13.10)	10.36	(9.91, 10.88)
Primary schools	12.80	(11.32, 14.12)	10.74	(10.09, 11.65)
Middle schools	11.09	(9.06, 13.49)	9.46	(8.67, 10.23)
High schools	12.91	(10.08, 18.61)	11.08	(9.35, 13.37)
Secondary schools	12.74	(9.30, 18.40)	12.34	(10.92, 14.26)
9/12-year schools	10.36	(8.09, 12.54)	8.65	(7.76, 10.24)
Urban classifications				
Urban centre	2.06	(1.92, 2.18)	1.80	(1.73, 1.86)
Urban area	3.07	(2.89, 3.28)	2.74	(2.63, 2.85)
Suburb	15.95	(14.03, 18.33)	11.87	(10.93, 12.87)
School deprivation quintiles				
Q1 (Least deprived)	13.44	(11.24, 16.08)	12.15	(11.17, 13.58)
Q2	15.34	(12.56, 18.87)	13.64	(12.63, 15.13)
Q3	10.89	(9.36, 13.27)	9.20	(8.34, 10.22)
Q4	9.72	(8.45, 11.93)	7.87	(7.23, 8.56)
Q5(Most deprived)	13.21	(11.14, 15.62)	10.19	(9.13, 11.00)
Types of tobacco retailers				
Convenience stores	12.91	(11.72, 15.18)	10.88	(10.17, 11.38)
Supermarkets	9.58	(8.14, 11.56)	8.06	(7.62, 8.66)
Tobacco-only outlets	15.33	(13.03, 18.79)	13.22	(12.01, 14.73)

5.4.4 Retailer compliance with spatial restrictions

The compliance with spatial restrictions on prohibiting tobacco retail around public schools was examined by identifying whether at least one tobacco retailer was in the vicinity of the main entrance of public schools at a distance of 50 m (Table 5.4). Overall, 5.9% of schools were found to have at least one tobacco retailer within this distance. There were no significant differences in the types of public schools. The type of public school with the greatest proportion of illicit tobacco retailers was 9/12-year schools (8.3%), followed by primary schools (6.8%). High schools were the least exposed to illicit tobacco retail, with only 3.9% of them found with at least one tobacco retailer around.

Public schools in urban centre were found to have a higher probability of being exposed to illicit tobacco retail (12.1%) than those in urban area and suburb. A greater proportion of public schools in Q1 were found with at least one tobacco retailer around (8.4%), while a smaller proportion was found in Q4 (4.0%). Examining the retailer compliance by retail type, there were 3.9% of public schools exposed to illicit tobacco retail in convenience stores. Illicit tobacco retail in tobacco-only outlets was rare

(1.8%), while illicit tobacco retail in supermarkets was rarer still with a proportion of 0.9%.

For comparison, the proportion of public schools in the vicinity of a tobacco retailer was also calculated at a distance of 100m around the main entrance, there were 17.8% of public schools that had at least one tobacco retailer around. Still, with no significant differences, a greater proportion of 9/12-year schools were in the vicinity of a tobacco retailer (22.5%), followed by high schools (19.4%), which was the type of school with the least exposure to illicit tobacco retailers (3.9%), while the proportion of primary schools was rarer (18.5%). Following the same trend found within 50 m of the main entrance, at a distance of 100 m, more than 30% of public schools in urban centre were in the vicinity of a tobacco retailer. Similarly, by school deprivation quintiles, a greater proportion was found in Q2 (22.9%) and a smaller proportion in Q4 (13.1%). Among three types of tobacco retailers, a higher proportion of public schools were in the vicinity of a convenience store (11.9%). Unlike the pattern found within 50 m of the main entrance, public schools in the vicinity of tobacco retail in tobacco-only outlets became rarer (4.6%) than in supermarkets (5.5%).

Table 5.4 Proportion (%) of public schools in vicinity of tobacco retailers

	50 m	100 m
Types of schools		
All	5.9%	17.8%
Primary	6.8%	18.5%
Middle	5.7%	18.1%
High	3.9%	19.4%
Secondary school	4.1%	18.4%
9/12-year	8.3%	22.5%
Urban classifications		
Urban centre	12.1%	30.4%
Urban area	5.1%	17.6%
Suburb	4.0%	13.0%
School deprivation quintiles		
Q1(least deprived)	8.4%	21.9%
Q2	7.4%	22.9%
Q3	5.1%	13.5%
Q4	4.0%	13.1%
Q5(most deprived)	5.4%	17.6%
Types of tobacco retailers		
Convenience stores	3.9%	11.9%
Supermarkets	0.9%	5.5%
Tobacco-only outlets	1.8%	4.6%

5.5 Discussion

5.5.1 Summary of findings

This study of tobacco retail environments around public schools in Shanghai found that exposure to tobacco retail within 400 m and 800 m of the main entrance of public schools was substantial, with a high degree of spatial clustering of tobacco retailers. Further, a small proportion of public schools failed to comply with the spatial restriction even though the 50 m prohibiting zone is defined using such a sensitive distance.

5.5.2 Interpretation of key findings

Firstly, the great availability of tobacco retailers was found around schools, which is consistent with previous evidence from a range of countries (e.g. the US,²¹ Australia,⁵⁵ and Spain⁵⁶), as well as other cities in China.^{28,31} Moreover, as the most frequent type of tobacco retailer in Shanghai, it is no surprise that more convenience stores selling tobacco were found around public schools, but tobacco-only outlets were the more clustered type of tobacco retailer around public schools. A plausible explanation of this pattern is that the tobacco industry attempts to normalise smoking and encourage smoking initiation among students^{19,20} through tobacco-focused marketing within tobacco-only outlets even though students are not allowed to purchase tobacco products legitimately.^{57,58}

Previous findings from the US suggested more tobacco retailers tended to be located around high and middle schools within a distance of 800 m.²¹ At a distance of 800 m, nearly half of all tobacco retailers (45.9%) were found around primary schools in Shanghai, which is more similar to the pattern found in Thailand,⁵⁹ but a higher degree of spatial clustering was found around high schools and secondary schools, which may suggest secondary school (aged 12–18) and high school (aged 15–18) were among the primary targets of the tobacco industry.

Although tobacco retailers were more clustered around high schools and secondary schools across Shanghai, the proportion exposed to non-compliant tobacco retailers was smaller than other types of public schools. This finding may suggest the spatial

restrictions on tobacco retail around school areas were more strictly enforced around high schools and secondary schools by Shanghai TMB due to the importance of the group (aged 12–18) in terms of tobacco control. On the other hand, our study found a relatively high proportion of non-compliant tobacco retailers around primary schools which might imply that stricter enforcement of the spatial restrictions on tobacco retail around primary schools is required.

Previous studies in the US suggested being exposed to tobacco advertising, promotion, and sales at tobacco retailers close to school may distort perceptions of tobacco use and further increase the likelihood of smoking initiation among schoolchildren.^{58,60,61} Even though primary school students (aged 6-12) may not be the primary marketing target of the tobacco industry like high school students (aged 15-18), schools that are more saturated with tobacco retailers may serve to normalise tobacco use⁶² and increase environmental cues to smoking.^{57,63,64} Nevertheless, as the prohibiting distance increased to 100 m, as other Chinese cities have done (e.g. Beijing), the proportion of public schools that were found with at least one tobacco retailer increased 3-folds even though 100 m is also a sensitive distance that it is easy to be reached by students. Therefore, our study suggests that it is critical to enforce stricter restrictions, greater regulation, and enforcement on tobacco retail around school areas to prevent the marketing, advertising, and promotion of cigarettes around school.

Nian et al. (2022) reported that about 53.1% of schools (n = 128) in Shanghai were allocated with at least one tobacco retailer within 100 m-radius around the main entrance through randomly sampling 148 tobacco retailers around 128 schools.³² However, our study suggested it was 17.8% of public schools had at least one tobacco retailer within 100 m-radius. Considering our study included a more complete sample of tobacco retailers (n = 1,9413) and public schools (n = 1,483), the inconsistency in findings could be attributed to the simple sampling approach, which neglected the complexity of social structure and geographical differences in a megacity, resulting in a biased sample of tobacco retailers and public schools. In addition, considering our study used network analysis to simulate the walking environment around schools, our findings may provide a more accurate estimation of the tobacco retail environment around public schools across the metropolitan area of Shanghai.

5.5.3 Limitations

The present research has some limitations. Firstly, the imperfect alignment between the census units (i.e. residential communities) used to calculate the neighbourhood deprivation index and the designated school catchment areas (i.e. divided by road) may lead to some misclassifications in the school deprivation index. Secondly, it is feasible that our measure may have underestimated compliance (Figure 5.2). According to the regulation, only the retailer that was located along the road directly towards the main entrance (Retailer 2) would be treated as an illicit tobacco retailer. But in the analysis, both Retailer 1 and Retailer 2 were allocated within the 0-50 m buffer around the main entrance of the school. However, no other more accurate approach could be used to examine the non-compliance due to the difficulty in taking road networks into account. This "overstatement" is also the result of the ambiguous description in the spatial restriction made by TMB. For future studies, we may consider the possibility of examining the specific impacts of the tobacco retail environment around schools on smoking behaviours among students if geographically-specific smoking data among students, which could be linked to public schools, is available.

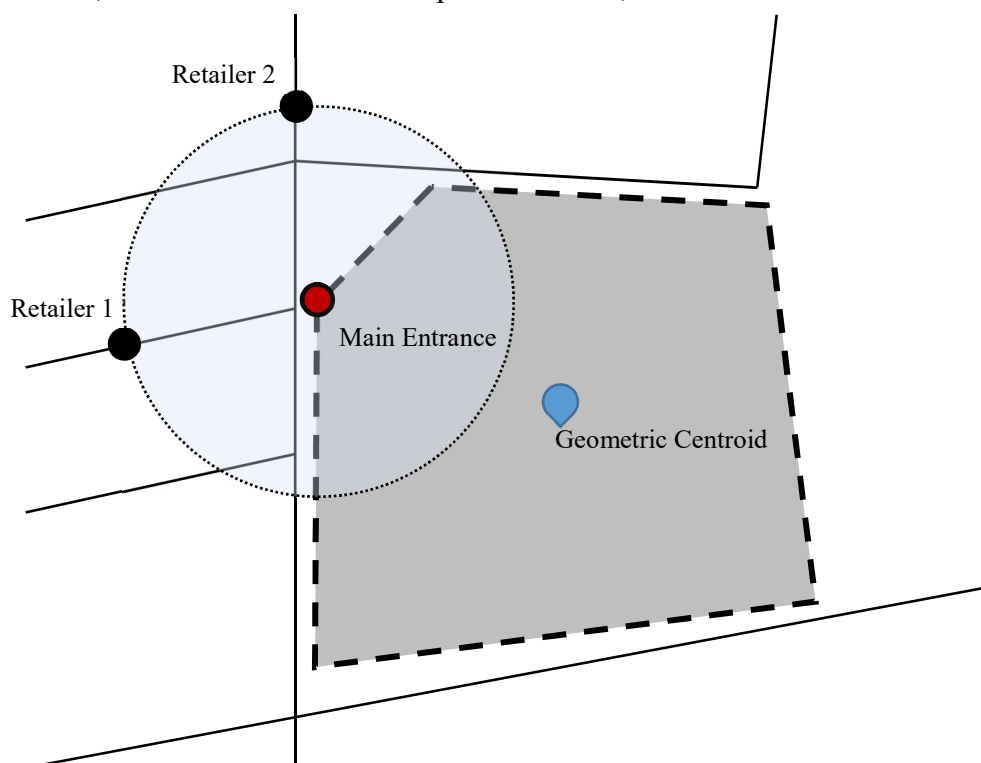


Figure 5.2 The potential bias in examining the compliance of tobacco retailers with spatial restrictions for tobacco retail

5.6 Conclusion

In the setting of the mega-city of China, the present research found the high availability and high degree of clustering of tobacco retailers around public schools in Shanghai, indicating the current tobacco retail environment may impose negative impacts on students around school areas. This work further evaluated the compliance of tobacco retailers to spatial restrictions aiming at prohibiting tobacco sales around public schools, revealing a relatively lower compliance rate for primary schools as compared to secondary schools. Our study suggests that more attention should be paid to supervising the enforcement of spatial restrictions around primary schools and 9/12-year schools by local tobacco control authorities. In addition to a particular focus on high and secondary schools, policymakers should strengthen the enforcement of spatial restrictions on tobacco retail around all types of schools and further consider exploring comprehensive strategies for reducing tobacco retail density and proximity to schools, especially in more urbanised areas.

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5.8 Supplementary Materials: Construct School Deprivation Index

Appendix I. Estimate school catchment areas

To examine the social disparities in the tobacco retail environment around public schools in Shanghai, the school deprivation index was constructed using the population-weighted neighbourhood deprivation index of the school catchment areas.

Students in Years 1-9 of Shanghai are supposed to be enrolled in public schools nearby. Therefore, all public schools in Shanghai in Years 1-9 have designated school catchment areas. However, due to the imperfect alignment in census units (by residential community) used to calculate the neighbourhood deprivation index and the unit of designed school catchment areas (by road), in addition to the unavailability of catchment areas for public schools in Years 10-12 (the enrolment of public schools in Years 10-12 is decided by the academic performance of students and the *hukou* registered district rather than school catchment areas), the Huff model was applied to estimate the approximate school catchment areas for all public schools in Shanghai, to further calculate the school deprivation index.

The Huff model is one of the most popular population catchment area models, which has been widely applied in areas including retail and services.¹⁻³ As a probabilistic market area model, the major advantage of the Huff model is that it allows for the simultaneous estimation of a customer's patronage probabilities for many retail centres.⁴ Adapted from Pavlis et al. (2014)⁵ and Dolega et al. (2016),¹ in our case, for school catchment area estimation, the Huff model could be calculated according to the following equation:⁵

$$p_{ij} = \frac{A_j^\alpha D_{ij}^{-\beta}}{\sum_{j=1}^n A_j^\alpha D_{ij}^{-\beta}}$$

Where p_{ij} is the probability of students' decisions on school enrolment from the centroid of a residential community i on the public school j ($0 < p_{ij} < 1$, $\sum_{j=1}^n p_{ij} = 1$), A_j is the attractiveness measure of the public school j , α is the

exponent of the attractiveness parameter, D_{ij} is the pairwise distance from i to j , β is the exponent of distance.

In our study, specifically, the attractiveness of a public school was measured by the enrolled number of new students at each public school in 2019. Considering the 15 min life zone policy of Shanghai, 1.5 km (a plausible 15 min walking distance) was selected as the threshold to define the access from the centroids of a residential community to a public school. A public school within a maximum of 1.5 km of the centroid of a residential community was assumed to be a primary destination for students, and hence the attractiveness score exponent (α) for that pair was raised to a power of two, while a default value of 1 was used for other distances. The pairwise distance D_{ij} was calculated using the OD cost matrix analysis based on the road network of Shanghai acquired from OpenStreetMap. Following previous studies, the beta exponent (β) took a value of between -1 and -2,¹ depending on the level of attractiveness of public schools. The beta exponent (β) value of public schools that were allocated within a maximum of 1.5 km of the centroid of a residential community was assigned a value of -2, while others were assigned a value of -1.

Since students are required to enrol in public schools in the same district as their residential community, the school catchment area estimation was performed for each district of Shanghai ($n = 16$). Additionally, the school catchment areas for schools in Years 1 to 5 (i.e. primary school and 9/12-year school), schools in Years 6 to 9 (i.e. middle school and 9/12-year school), and schools in Years 10-12 (i.e. high school, secondary school, and 9/12-year school) were estimated within each district of Shanghai, respectively. To simulate the proper school catchment areas, two criteria were applied: (1) the simulated school catchment areas of all public schools should cover all residential communities within districts; and (2) the school catchment areas should have the highest range of probabilities that were calculated using the Huff model. Therefore, all probabilities within each district for different school years were grouped into percentiles. The probabilities for schools in Years 1-5 ranged from 14th to 100th percentile, while the probabilities for schools in Years 6-9 ranged from 35th to 100th percentile, and the probabilities for schools in Years 10-12 ranged from 39th to 100th percentile.

Appendix II. Population-weighted school deprivation index

In the final stage, the population-weighted means of the neighbourhood deprivation indices of each approximate school catchment area were calculated to reflect the school deprivation index.

Sourcing from the 2010 Chinese census of China at the residential community-level (akin to a residential neighbourhood), referencing established international indices such as the Carstairs and Townsend indices and previous studies in China, four residential community-level indicators, including unemployment rate, low-skilled worker rate, low-educational attainment rate, and non-homeownership rate, were summed up using the equal-weighting approach after standardising. A higher score indicates a higher level of neighbourhood deprivation.

Further, the school deprivation indices of all public schools in Shanghai were grouped into quintiles, where the 1st quintile is the least deprived school catchment areas, while the 5th quintile is the most deprived school catchment areas. The school deprivation index was calculated as follows:

$$DI_i = \frac{\sum_{j=1}^n (DI_j \times pop_j)}{\sum_{j=1}^n pop_j}$$

Where for each catchment area of public school i , DI_i is the population-weighted school deprivation index value, n is the total number of residential communities within each catchment area. DI_j and pop_j are the neighbourhood deprivation index and the population of students (aged 5-19) of the j th residential community within catchment area i .

Appendix III. Proportion of public schools in vicinity of tobacco retailers

	400 m	800 m
Types of schools		
All	79.2%	95.8%
Primary	83.1%	96.3%
Middle	75.7%	95.8%
High	74.4%	94.6%
Secondary school	77.6%	93.9%
9/12-year	74.5%	95.5%
Urban classification		
Urban centre	94.1%	100%
Urban area	86.1%	99.2%
Suburb	67.9%	91.6%
School deprivation quintiles		
Q1(least deprived)	86.9%	99.0%
Q2	86.5%	97.6%
Q3	78.4%	96.6%
Q4	70.0%	92.3%
Q5(most deprived)	73.3%	93.2%
Types of tobacco retailers		
Convenience stores	65.9%	89.7%
Supermarkets	55.2%	91.0%
Tobacco-only outlets	46.1%	81.3%

Reference

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**Chapter 6 A cross-sectional and longitudinal analysis
of neighbourhood effects of tobacco retail availability
and neighbourhood deprivation on smoking
behaviours among men in Shanghai, China**

6.1 Abstract

Background. International evidence suggests tobacco retail availability and neighbourhood deprivation may influence smoking behaviours. However, this assertion has not been considered in China, where smoking prevalence remains high, particularly for males.

Methods. Data were analysed from Chinese males ($n = 2054$) who participated in Waves 3-5 (2009-2015) of the International Tobacco Control China Survey. Data were linked to 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. Multilevel logistic regressions were fitted to examine the cross-sectional impacts of availability and deprivation on smoking behaviours (never smoker, current smoker, non-daily smoker, daily smoker, and quitter) among Chinese men while General Estimating Equation models were fitted to examine the longitudinal impacts.

Results. Cross-sectionally, better availability was associated with greater odds of current smoking, while deprivation was positively associated with current smoking and negatively associated with longer duration of abstinence. Longitudinally, higher availability and deprivation were associated with reduced odds of a longer duration of abstinence. After controlling for individual covariates, availability was only associated with increased odds of non-daily smoking while higher deprivation was associated with increased odds of current smoking. Additionally, among cross-sectional and longitudinal models, the impacts of availability on smoking differed by urbanity level and deprivation level.

Conclusions. Tobacco retail availability and deprivation are positively associated with smoking and negatively associated with smoking cessation cross-sectionally and longitudinally among males in Shanghai, China. Policymakers should consider reducing the availability of tobacco in China as part of a comprehensive tobacco control strategy aimed at reducing the high prevalence of smoking.

6.2 Introduction

In China, with over 1 million smoking-attributable deaths each year, addressing the tobacco epidemic remains a major public health challenge.¹⁻³ Despite some recent successes in implementing tobacco control initiatives and subsequent small reductions in smoking prevalence, 44.4% of men in China continue to smoke.⁴

Increasing international evidence suggests that individual smoking behaviours could be influenced by a number of place-based characteristics⁵ such as: neighbourhood deprivation or disadvantage,⁶⁻¹³ availability of tobacco products,^{8,14-16} local social norms,¹¹ social cohesion,¹⁷⁻¹⁹ neighbourhood disorder and perception of crimes,¹⁹⁻²¹ and levels of urbanity.²² From a policymaking perspective, specifying the local geographical processes shaping smoking practices provides opportunities for reducing smoking prevalence and smoking-related health inequalities.²³

One local geographical characteristic that could affect individual-level smoking is neighbourhood deprivation. Previous research from high-income countries (HICs) suggests living in a more socioeconomically deprived neighbourhood is associated with higher levels of smoking^{6,24} and a lower likelihood of quitting.⁷ However, research from other settings shows mixed results. In Mexico, lower smoking intensity was associated with higher-level neighbourhood deprivation, while more quit attempts showed a U-shaped pattern,¹³ while 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 deprivation index.²⁵ 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 neighbourhood) within 9 provinces found that neighbourhood social development was negatively associated with smoking frequency in 1989-2011.²⁶ A cross-sectional study using a more recent wave (2015) of the same survey (228 communities within 12 provinces) found neighbourhood deprivation was positively associated with smoking intensity.²⁷ However, 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 on smoking at regional or city-level.

Tobacco retail availability is another neighbourhood characteristic that has been associated with smoking behaviours. Greater local availability of tobacco has been shown to contribute to tobacco consumption,^{8,14,15} a higher likelihood of smoking initiation or continued smoking, and lower odds of cessation^{10,23} 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.⁵ 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 smoking⁸ and a lower likelihood of smoking cessation.²⁸ Similarly, increased density of tobacco outlets was associated with decreased odds of intention to quit in high-income neighbourhoods of Canada.²⁹ 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.¹⁴ 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.²³ 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 remain rare. In the context of China, recent studies found a positive association between regional tobacco production and individual smoking behaviours,³⁰ as well as a positive association between city-level tobacco retail density and second-hand smoke exposure.³¹ However, evidence regarding the impact of neighbourhood-level tobacco retail density on individual smoking is still absent.

Understanding the influence of neighbourhood socio-commercial impacts on smoking behaviours is important for developing policies to address the tobacco epidemic and reducing tobacco-related inequalities between social groups,³² particularly in countries like China where the prevalence of smoking is extremely high. Under a transitional economy and rapid urbanisation, the socio-spatial structure and tobacco consumption pattern in cities of China have experienced considerable changes. Megacities like Shanghai are more advanced in this transformation and may share similarities with

what has been documented in HICs. Given the findings from China and other settings, 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. Therefore, this study uses longitudinal data to assess the impacts of neighbourhood-level socio-commercial characteristics including availability of tobacco retail and deprivation on smoking-related behaviours, cross-sectionally and longitudinally. The following questions are considered:

- What is the relationship between tobacco retail availability, neighbourhood deprivation and smoking behaviours?
- Do relationships between tobacco retail availability and smoking behaviours vary by levels of urbanity and levels of neighbourhood deprivation?

6.3 Methods

6.3.1 Study Samples

The study used data from the International Tobacco Control China Survey (ITC China), a population-based longitudinal survey in 12 cities of China, including Shanghai.³³ Launched in 2006 (wave 1), the survey used a stratified multistage cluster sampling design.³³ Using the randomised probability proportional to population size sampling, 20 residential communities from 10 subdistricts were randomly chosen in each city.³⁴ Within each selected residential community, adults from 300 households were approached and surveyed randomly until 40 smokers and 10 never-smokers were identified,³⁴ eventually obtaining a total sample of 800 adult smokers and 200 adult never-smokers across the city of Shanghai in wave 1.³⁴ 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.³⁴ Respondents from new residential neighbourhoods/sub-districts were added following the framework of wave 1.³⁴

To examine the neighbourhood effects on individual-level smoking, we used data from wave 3-5 (2009-2015) since the explanatory variables were obtained from 2010 (i.e. deprivation) and 2019 (i.e. availability), respectively. For the cross-sectional analyses, a total sample of 1020 respondents residing within 29 residential neighbourhoods of Shanghai from wave 5 was included. The longitudinal 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. Among the sample for longitudinal analysis, 1656 out of 2420 respondents had data for all 3 waves. Sample characteristics are described in Table 6.1.

There is a large gender disparity in smoking prevalence in China (50.5% of men and 2.1% of women).⁴ Although the ITC China has tried to increase the sample size for women by surveying one male smoker and one female smoker from every selected household whenever possible,³⁴ in Shanghai, the proportion of female current smokers constituted only 2.53% of the total sample across all 5 waves. Therefore, our study

only focused on the neighbourhood effects on smoking among men, which left a total of 867 cross-sectional male samples and 2054 longitudinal male samples.

6.3.2 Measures

6.3.2.1 *Smoking status*

Five measures of smoking status were calculated for each respondent to capture current and past smoking behaviour, including measure of smoking intensity.

At the time of survey, the smoking status of each respondent was coded as smoker (“smoked cigarettes at least monthly and had smoked 100 or more cigarettes in their lifetime”), quitter (“smokers who had quit for a period of time”), and never-smoker.^{35,36} 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. Further, 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. Finally, to determine the impacts of availability and deprivation on smoking intensity, each smoker was categorised as a “daily smoker” or “non-daily smoker” (“Do you smoke every day or some days?”). Thus, two other outcomes regarding smoking were included: 1) non-daily smoking versus current non-smoking; 2) daily smoking versus non-daily smoking.

6.3.2.2 *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 geocoordinates of Point of Interests (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 searching radius of 10-min walking distance (800 m). The KDE value represents the smoothed density of tobacco retailers in Shanghai. Further, values of KDE in the grid cells were extracted into the centroids of subcommunities

and weighted by the total population of each subcommunity which was sourced from the 2010 Chinese census of Shanghai, representing the density of tobacco retailers per residential community per km² per neighbourhood. A high availability index suggests the greater availability of tobacco retailers within residential neighbourhoods. Tobacco retail availability was treated as a continuous explanatory variable after mean centring.

6.3.2.3 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,³⁷ all census-based neighbourhood indicators were weighted equally and summed after standardising through z-score. A higher score of neighbourhood deprivation indicates a higher level of neighbourhood deprivation. Neighbourhood deprivation indices were considered as a continuous explanatory variable.

6.3.2.4 Individual-level Covariates

Potential factors that could confound the association between explanatory and outcome variables were controlled in the adjusted models. Age was treated as a continuous variable, with the further adjustment of age squared to capture the potential non-linear pattern. 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 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 subset of each covariate.

6.3.2.5 Neighbourhood-level covariates

Levels of urbanity (urban centre versus urban area) and levels of deprivation (lower deprivation versus higher deprivation) were introduced as neighbourhood-level covariates for all outcome variables. All neighbourhoods across Shanghai were classified as ‘urban centre’, ‘urban area’, and ‘suburb’ based on the road network of Shanghai following prior research.³⁸ The levels of urbanity decreased from urban centre neighbourhoods to urban area neighbourhoods, and to suburb neighbourhoods. Our study examined the association between tobacco retail availability and smoking behaviours by urban centre and urban area neighbourhoods since the ITC Shanghai only surveyed residential communities in urban centre and urban areas of Shanghai.

Tobacco retail availability was found to be highly correlated with deprivation ($p < 0.001$). Therefore, to examine whether the impacts of tobacco retail availability on smoking behaviours varied by levels of neighbourhood deprivation, all residential communities that have been investigated were grouped as less deprived or more deprived neighbourhoods using the median of neighbourhood deprivation indices.

6.3.3 Statistical Analysis

Descriptive statistics were applied to characterise variables of interest in analytic samples among men. The cross-sectional relationships between availability, deprivation and each outcome variable regarding smoking behaviours were tested using multilevel logistic regression with random intercepts (respondents at level 1 nested within neighbourhoods at level 2). Generalised Estimating Equation (GEE) with an exchangeable working correlation matrix and robust standard errors clustered at the neighbourhood-level was used to test the impacts of availability and deprivation on each outcome of interest over time. Finally, for the longitudinal analyses, “wave” was introduced as a categorical explanatory variable in the model to model the changes in each outcome of interest across time, further adjusted by tobacco retail availability and other covariates. We also conducted sensitivity analyses among a larger sample of respondents, including the females who were excluded from the main study (see Appendix I).

All statistical analyses were performed in Stata/IC 13. Sampling weights were not accounted for, considering the interest in this specific subpopulation in the given geographical areas.

6.4 Results

6.4.1 Sample characteristics

Table 6.1 describes the sample characteristics of each analytic sample by smoking status, individual-level socio-demographics, tobacco retail availability, and deprivation. For sample 1 ($n = 867$), the majority of the cross-sectional male respondents were daily smokers (78.2%). The sample members had an average age of 55.3, slightly over half with medium-level education (51.7%) and over a third with high household income (34.3%). About 40% of cross-sectional respondents resided in urban centre neighbourhoods while 52.3% of them lived in less deprived neighbourhoods.

The characteristics of the longitudinal samples were reported separately by the respondents who had data for three waves (Sample 2) and the respondents with two waves of data (Sample 3). Among Sample 2 and Sample 3, most of the respondents were daily smokers, with medium-level education and medium-low level household income. Compared with Sample 2, a greater proportion of respondents in Sample 3 were daily smokers (82.8%), with a higher mean age (55.4). 61.1% of Sample 2 was living in urban centre neighbourhoods while it was 46.1% in Sample 3. More respondents from Sample 2 resided in less deprived neighbourhoods (56.9%) while more respondents from Sample 3 were found in more deprived neighbourhoods (59.6%).

6.4.2 Cross-sectional models

Table 6.2 presents results from models for the cross-sectional effects of availability and deprivation on each outcome of interest. In M1a, availability was only associated with greater odds of current smoking versus current non-smoking ($OR = 1.03$, 95%CI = 1.00, 1.07). After controlling for individual-level covariates (M2a), the significant positive association between availability and current smoking remained ($OR = 1.04$, 95%CI = 1.00, 1.07). M1b examines the unadjusted association between neighbourhood deprivation and each outcome of interest. Higher deprivation was found to be associated with higher odds of current smoking ($OR = 1.23$, 95%CI = 1.05,

1.07), with lower odds of longer duration of abstinence (OR = 0.63, 95%CI = 0.46, 0.98). These significant associations were retained within the adjustment of individual-level covariates (M2b).

6.4.3 Longitudinal models

Table 6.3 presents the relationship between tobacco retail availability, deprivation, and each outcome of interest over time. Among M1a, across waves, availability was only significantly associated with a longer duration of abstinence (versus current smoking) (OR = 0.94, 95%CI = 0.89, 0.99). After controlling for covariates (M2a), availability was significantly associated with increased odds of non-daily smoking when compared with non-current smoking (OR = 1.06, 95%CI = 1.00, 1.12) while the significant association between availability and longer duration of abstinence disappeared. In terms of the unadjusted association with neighbourhood deprivation, higher deprivation was associated with increased odds of current smoking (OR = 1.16, 95%CI = 1.01, 1.33) and decreased odds of longer duration of abstinence (OR = 0.74, 95%CI = 0.62, 0.88). Although the impact of availability and deprivation on quitting (versus current smoking) was tested over time, there was no significant association that could be found from all sets of models.

6.4.4 Stratified models

Cross-sectionally (Table 6.2), higher availability was associated with greater odds of current smoking (OR = 1.05, 95%CI = 1.01, 1.09) and smaller odds of quitting (OR = 0.96, 95%CI = 0.92, 1.00) in urban centre neighbourhoods while higher availability was found to be associated with greater odds of daily smoking when compared with non-daily smoking in urban area neighbourhoods (OR = 1.14, 95%CI = 1.00, 1.29) and less deprived neighbourhoods (OR = 1.22, 95%CI = 1.05, 1.43).

Longitudinally (Table 6.3), higher availability was associated with increased odds of non-daily smoking in urban centre neighbourhoods (OR = 1.07, 95%CI = 1.00, 1.14) while daily smoking was found to be associated with availability in more deprived neighbourhoods when compared with non-daily smoking (OR = 1.02, 95%CI = 1.00, 1.05). A significant association between higher availability and decreased odds of

longer duration of abstinence was found in urban centre neighbourhoods (OR = 0.90, 95%CI = 0.82, 0.99). Among stratified models, availability was not found to be associated with quitting.

6.4.5 Time-varying model

Table 6.4 demonstrates smoking status varying across waves. Compared with respondents from wave 3, respondents from wave 5 were associated with decreased odds of current smoking in both unadjusted and adjusted models. The odds of non-daily smoking and daily smoking were not found to be associated with wave. For smoking cessation, each wave was significantly associated with quitting and a longer duration of abstinence for each wave in unadjusted models. In adjusted models, only wave 5 was found to be significantly associated with increased odds of quitting while the significant association between waves and longer duration of abstinence by each wave was retained.

6.4.6 Sensitivity analysis

The majority of the results of the sensitivity analyses agreed with the main study (Appendix I, II, III, IV) except for the association between tobacco retail availability and quitting that higher availability was found to be associated with increased odds of quitting over time (Appendix III) while there was no such relationship could be found in the main study.

Table 6.1 Characteristics of study population (men only)

	Sample 1: Cross-sectional sample in Wave 5 (n=867)	Sample 2: Respondents participated 3-wave investigations (n=1356, 452 respondents per wave)	Sample 3: Respondents participated 2-wave investigations (n=698)
Smoking status, n(%)			
Never-smoker	75 (8.65)	156 (11.50)	50 (7.16)
Non-daily smoker	30 (3.46)	36 (2.65)	25 (3.58)
Daily smoker	678 (78.20)	1,042 (76.84)	578 (82.81)
Quitter with shorter duration of abstinence	54 (6.23)	65 (4.79)	36 (5.16)
Quitter who has quit since the last wave	30 (3.46)	57 (4.20)	9 (1.29)
Age in years, mean(SE)	55.29 (0.37)	53.28 (0.28)	55.35 (0.46)
Levels of education, n(%)			
Low	356 (41.06)	520 (38.35)	269 (38.54)
Medium	448 (51.67)	721 (53.17)	380 (54.44)
High	61 (7.04)	113 (8.33)	49 (7.02)
NA	2 (0.23)	2 (0.15)	---
Levels of household income per month, n(%)			
Low	62 (7.15)	266 (19.62)	151 (21.63)
Medium low	152 (17.53)	429 (31.64)	205 (29.37)
Medium high	292 (33.68)	298 (21.98)	162 (23.21)
High	297 (34.26)	296 (21.83)	146 (20.92)
NA	64 (7.38)	67 (4.94)	34 (4.87)
Tobacco retail availability index, mean (SE)	22.23 (0.42)	18.33 (0.11)	22.67 (0.46)
Neighbourhood deprivation index, mean(SE)	-0.63 (0.07)	-1.49 (0.04)	-0.11 (0.09)
Levels of urbanity			
Urban centre	347 (40.02)	528 (38.94)	322 (46.13)
Urban area	520 (59.98)	828 (61.06)	376 (53.87)
Levels of deprivation			
Low	453 (52.25)	771 (56.86)	282 (40.40)
High	414 (47.75)	585 (43.14)	416 (59.60)

Table 6.2 Cross-sectional associations between tobacco retail availability, neighbourhood deprivation and smoking behaviours (men only)

	Current smoking versus current non-smoking	Non-daily smoking versus current non-smoking	Daily smoking versus non- daily smoking	Quitting versus current smoking	Longer duration of abstinence versus current smoking
	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
M1a. Availability	1.03 (1.00, 1.07)*	1.06 (0.99, 1.14)	1.01 (0.97, 1.04)	0.98 (0.94, 1.01)	0.92 (0.83, 1.02)
M1b. Deprivation	1.23 (1.05, 1.43)**	1.40 (0.92, 2.12)	1.02 (0.79, 1.32)	0.86 (0.71, 1.04)	0.63 (0.46, 0.87)**
M2a. Availability	1.04 (1.00, 1.07)*	1.07 (0.96, 1.18)	1.01 (0.97, 1.04)	0.98 (0.94, 1.01)	0.93 (0.85, 1.02)
M2b. Deprivation	1.21 (1.03, 1.42)*	1.48 (0.85, 2.58)	1.03 (0.79, 1.34)	0.86 (0.70, 1.05)	0.68 (0.49, 0.93)**
M3a. Availability	1.05 (1.01, 1.09)**	1.06 (0.97, 1.16)	1.01 (0.97, 1.05)	0.96 (0.92, 1.00)*	0.89 (0.79, 1.01)
M3b. Availability	0.97 (0.88, 1.07)	1.28 (0.80, 2.05)	1.14 (1.00, 1.29)*	1.09 (0.97, 1.24)	1.05 (0.85, 1.29)
M4a. Availability	0.99 (0.91, 1.09)	1.27 (0.98, 1.64)	1.22 (1.05, 1.43)*	1.04 (0.90, 1.20)	0.98 (0.82, 1.17)
M4b. Availability	1.03 (0.99, 1.08)	1.01 (0.91, 1.12)	0.99 (0.95, 1.02)	0.97 (0.94, 1.01)	0.92 (0.81, 1.05)

Note: CI = Confidence Interval; Statistical significance level: *0.05, **0.01

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. In addition to the main effect models, the fully-adjusted association between tobacco retail availability and each outcome variable were stratified by levels of urbanity (M3a: urban centre, M3b: urban area) and levels of deprivation (M4a: less deprived, M4b: more deprived).

Table 6.3 Longitudinal associations between tobacco retail availability, neighbourhood deprivation and smoking behaviours (men only)

	Current smoking versus current non-smoking	Non-daily smoking versus current non-smoking	Daily smoking versus non- daily smoking	Quitting versus current smoking	Longer duration of abstinence versus current smoking
	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
M1a. Availability	1.02 (0.99, 1.04)	1.05 (1.00, 1.10)	1.03 (1.00, 1.05)	0.98 (0.96, 1.01)	0.94 (0.89, 0.99)*
M1b. Deprivation	1.16 (1.01, 1.33)*	1.18 (0.99, 1.41)	1.02 (0.84, 1.25)	0.91 (0.79, 1.04)	0.74 (0.62, 0.88)**
M2a. Availability	1.02 (0.98, 1.05)	1.06 (1.00, 1.12)*	1.02 (1.00, 1.05)	0.99 (0.96, 1.02)	0.95 (0.90, 1.01)
M2b. Deprivation	1.13 (1.01, 1.26)*	1.20 (0.98, 1.47)	1.05 (0.89, 1.23)	0.96 (0.84, 1.10)	0.82 (0.66, 1.02)
M3a. Availability	1.03 (0.99, 1.07)	1.07 (1.00, 1.14)*	1.02 (0.99, 1.04)	0.97 (0.93, 1.01)	0.90 (0.82, 0.99)*
M3b. Availability	0.94 (0.86, 1.02)	1.04 (0.91, 1.18)	1.09 (0.99, 1.20)	1.06 (0.96, 1.17)	1.00 (0.87, 1.16)
M4a. Availability	0.94 (0.86, 1.03)	1.06 (0.93, 1.20)	1.08 (0.95, 1.24)	1.08 (0.97, 1.20)	0.99 (0.89, 1.12)
M4b. Availability	1.02 (0.98, 1.07)	1.04 (0.98, 1.11)	1.02 (1.00, 1.05)*	0.98 (0.94, 1.02)	0.95 (0.88, 1.02)

Note: CI = Confidence Interval; Statistical significance level: *0.05, **0.01

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. In addition to the main effect models, the fully-adjusted association between tobacco retail availability and each outcome variable were stratified by levels of urbanity (M3a: urban centre, M3b: urban area) and levels of deprivation (M4a: less deprived, M4b: more deprived).

Table 6.4 The association between tobacco retail availability and smoking behaviours adjusted through wave indicator (men only)

	Current smoking versus current non-smoking	Non-daily smoking versus current non-smoking	Daily smoking versus non- daily smoking	Quitting versus current smoking	Longer duration of abstinence versus current smoking
	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
M5a. Wave (unadjusted)					
Wave 3	Reference group	Reference group	Reference group	Reference group	Reference group
Wave 4	0.98 (0.80, 1.19)	1.05 (0.59, 1.88)	0.98 (0.60, 1.59)	1.49 (1.01, 2.19)*	2.43 (1.18, 4.99)*
Wave 5	0.64 (0.53, 0.76)**	0.60 (0.36, 1.01)	0.83 (0.52, 1.31)	3.19 (2.06, 4.94)**	3.88 (1.65, 9.12)**
M5b. Wave (adjusted)					
Wave 3	Reference group	Reference group	Reference group	Reference group	Reference group
Wave 4	0.98 (0.75, 1.28)	1.10 (0.57, 2.13)	0.95 (0.56, 1.60)	1.37 (0.87, 2.16)	2.02 (1.08 3.78)*
Wave 5	0.57 (0.42, 0.76)**	0.53 (0.27, 1.07)	0.91 (0.48, 1.72)	2.83 (1.76, 4.55)**	2.87 (1.46, 5.66)**

Note: CI = Confidence Interval; Statistical significance level: *0.05, **0.01

M5a only included wave as the explanatory variable for each outcome variable while tobacco retail availability and individual-level covariates were controlled in M5b.

The significant association between tobacco retail availability and non-daily smoking with the adjustment of individual-level covariates in the longitudinal model was retained in the time-varying model.

6.5 Discussion

6.5.1 Summary of key findings

This is the first Chinese study to examine the cross-sectional and longitudinal impacts of tobacco retail availability on a series of smoking behaviours. Using the male adult sample of ITC, Shanghai, the biggest megacity of China, our study revealed that tobacco retail availability and deprivation were associated with individual-level smoking behaviours. Cross-sectionally, males living in neighbourhoods with better availability or higher deprivation were more likely to become current smokers and less likely to maintain a long-term duration of abstinence. Longitudinally, individual-level smoking status varied across waves. Males living in neighbourhoods with better availability were more likely to become non-daily smokers and less likely to quit. On the other hand, males living in neighbourhoods with higher deprivation were more likely to become current smokers and less likely to maintain a longer duration of abstinence. Finally, the association between tobacco retail availability and individual-level smoking behaviours varied by levels of urbanity and deprivation.

6.5.2 Interpretation of key findings

Our findings align with some previous findings from HICs. We found a significant cross-sectional association between tobacco retail availability and current smoking, which is broadly consistent with work in Scotland,²³ Australia,³⁹ and the US,⁴⁰ where higher tobacco retail density was associated with a higher likelihood of current smoking. However, in our work, this significant association became non-significant over a longer duration of time in China. A plausible explanation for this pattern may be that data on tobacco retail availability and individual-level smoking status were close in time in cross-sectional models, which resulted in a more significant association as compared to longitudinal models where variables were more separated in time.⁴¹ Specifically, the cross-sectional sample was taken from the most recent wave of data (Wave 5: 2013-2015) while availability data was collected in 2019; therefore, the impact was weakened after including samples from previous waves (Wave 3: 2009, Wave 4: 2011-2012) in the longitudinal models. In addition, the time-varying models

suggested there was a decline in the likelihood of smoking over time, which might also contribute to this pattern.

Previous studies showed mixed results regarding the impact of tobacco retail availability on smoking cessation. Higher-level availability was found to be associated with a lower likelihood of quitting in Scotland,²³ but with no significant association found in England.⁴² In the US, Retzeil et al. found negative impacts of availability on cessation²⁸ while Kong et al. found this impact was non-significant.⁴⁰ Our study demonstrated a significant association between availability and quitting across waves, but its cross-sectional association was non-significant. This pattern could be connected with the time-varying model that suggests the likelihood of smoking cessation increases across waves. Furthermore, this finding may indicate that tobacco retail availability has stronger impacts on cessation over time when compared with cross-sectional impacts.

Cantrell et al. (2015) found tobacco retail availability was associated with a reduced likelihood of quitting in high poverty areas of the US¹⁰ while the increased availability was associated with a lower likelihood of having quit attempts in high-income neighbourhoods in Canada.²⁹ In our study, in urban centre neighbourhoods only, a negative impact of availability on quitting (cross-sectional) and a negative impact on long-term durations of smoking abstinence (longitudinal) were found, with no significance found in less or more deprived neighbourhoods. These findings extend previous evidence about the impacts of tobacco retail availability on smoking and cessation.

The impact of neighbourhood deprivation on smoking behaviours agrees with previous findings from HICs such as the Netherlands,^{43,44} the UK,^{6,24} and the US^{8,45} that living in more deprived neighbourhoods was associated with a higher likelihood of current smoking. However, this finding is not entirely consistent with the previous findings in China. Our study did not find any significant association between neighbourhood deprivation and smoking intensity (non-daily smoking versus current non-smoking; daily smoking versus non-daily smoking). This disagreement may be because of the different sampling strategies of the dataset that were utilised as well as the categorisation of outcome variables. Yang et al. (2017)²⁶ and Chen et al. (2021)²⁷

used national samples and continuous outcome variables, whereas our research focused on the specific metropolitan area of Shanghai using binary outcomes.

6.5.3 Limitations

There are some limitations to this study. First, the explanatory variables including tobacco retail availability and neighbourhood deprivation, were acquired through a single measurement in different years. The tobacco retail availability index was calculated using data in 2019, while the neighbourhood deprivation index was constructed using the Chinese census of 2010. The possible socioeconomic changes that happened 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. Future research should consider using repeated measures of tobacco retail availability and deprivation at different time points for more accurate examinations. Second, because of the sampling strategy of ITC data, our study only examined the relationship between tobacco retail availability, neighbourhood deprivation, and smoking behaviours in urban centre and urban area neighbourhoods. Future research may consider a full coverage of neighbourhoods across Shanghai, including neighbourhoods in the urban periphery. Third, our study used different statistical methods for cross-sectional and longitudinal analyses since the sample size at the neighbourhood level was insufficient, which resulted in the non-convergence of 3-level logistic regression models when examining the effects over time. Besides, although all adjusted models were controlled for individual-level sociodemographic covariates, residual confounding remains a possibility.

6.6 Conclusion

Our present findings demonstrate the positive impacts of tobacco retail availability and neighbourhood deprivation on smoking and their negative impacts on smoking cessation, suggesting local policymakers should consider implementing comprehensive tobacco control strategies, especially spatial restrictions on tobacco retail at the neighbourhood level. Although a reduced likelihood of current smoking and an increased likelihood of quitting were found in recent waves of data, the prevalence of smoking is still unacceptably high. As a party to the WHO Framework Convention on Tobacco Control, stricter restrictions on tobacco retail are anticipated to further control tobacco consumption.

Reducing smoking prevalence and the related health inequalities, which are one of the aims of *Healthy China 2030*,⁴⁶ requires greater efforts. 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 are still absent. Under national-level guidelines, the local Tobacco Monopoly Bureau (TMB) of China has the authority to design and enforce regulations regarding tobacco retail and tobacco control. Therefore, regional/city-level evidence on how geographical processes affect smoking could provide useful insights for designing effective spatial restrictions for further tobacco control.

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6.8 Supplementary Materials

Appendix I. Characteristics of study population for the full sample (men and women)

	Sample 1: Cross-sectional sample in Wave 5 (n=1,020)	Sample 2: Respondents participated 3- wave investigations (n=1656)	Sample 3: Respondents participated 2- wave investigations (n=764)
Smoking status, n(%)			
Never-smoker	205 (20.10)	426 (25.72)	102 (13.35)
Non-daily smoker	33 (3.24)	37 (2.23)	25 (3.27)
Daily smoker	697 (68.33)	1066 (64.37)	592 (77.49)
Quitter with shorter duration of abstinence	54 (5.29)	66 (3.99)	36 (4.71)
Quitter who has quit since the last wave	31 (3.04)	61 (3.69)	9 (1.18)
Female, n(%)	153 (15.00)	300 (18.12)	66 (8.64)
Age in years, mean(SE)	55.35 (0.35)	53.43 (0.26)	55.37 (0.45)
Levels of education, n(%)			
Low	417 (40.88)	654 (39.49)	299 (39.14)
Medium	530 (51.96)	875 (52.84)	411 (53.80)
High	69 (6.76)	124 (7.49)	54 (7.07)
NA	4 (0.39)	3 (0.18)	0 (0)
Levels of household income per month, n(%)			
Low	77 (7.55)	345 (20.83)	171 (22.38)
Medium low	168 (16.47)	517 (31.22)	226 (29.58)
Medium high	335 (32.84)	354 (21.38)	172 (22.51)
High	358 (35.10)	351 (21.20)	159 (20.81)
NA	82 (8.04)	89 (5.37)	36 (4.71)
Tobacco retail availability index, mean (SE)	22.05 (0.39)	18.21 (0.10)	22.92 (0.46)
Neighbourhood deprivation index, mean(SE)	-0.64 (0.06)	-1.51 (0.04)	-0.06 (0.08)
Levels of urbanity			
Urban centre	418 (40.98)	642 (38.77)	366 (47.91)
Urban area	602 (59.02)	1014 (61.23)	398 (52.09)
Levels of deprivation			
Low	534 (52.35)	957 (57.79)	302 (39.53)
High	486 (47.65)	699 (42.21)	462 (60.47)

Appendix II. Cross-sectional associations between tobacco retail availability, deprivation and smoking behaviours (men and women)

	Current smoking versus current non-smoking	Non-daily smoking versus current non-smoking	Daily smoking versus non- daily smoking	Quitting versus current smoking	Longer duration of abstinence versus current smoking
	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
M1a. Availability	1.03 (1.00, 1.06)*	1.04 (0.98, 1.11)	1.00 (0.97, 1.04)	0.98 (0.94, 1.01)	0.92 (0.83, 1.02)
M1b. Deprivation	1.21 (1.04, 1.41)*	1.36 (0.88, 2.09)	1.01 (0.77, 1.33)	0.85 (0.70, 1.04)	0.63 (0.46, 0.87)**
M2a. Availability	1.03 (1.00, 1.07)*	1.06 (0.96, 1.16)	1.00 (0.97, 1.04)	0.97 (0.94, 1.01)	0.93 (0.85, 1.02)
M2b. Deprivation	1.22 (1.03, 1.46)*	1.46 (0.84, 2.53)	1.01 (0.77, 1.33)	0.86 (0.70, 1.06)	0.68 (0.50, 0.93)*
M3a. Availability	1.05 (1.01, 1.08)**	1.05 (0.98, 1.12)	1.00 (0.96, 1.04)	0.96 (0.92, 1.00)*	0.89 (0.79, 1.01)
M3b. Availability	0.96 (0.85, 1.08)	1.38 (0.71, 2.70)	1.13 (0.98, 1.30)	1.10 (0.97, 1.24)	1.05 (0.86, 1.29)
M4a. Availability	0.99 (0.91, 1.07)	1.27 (0.98, 1.64)	1.24 (1.05, 1.46)**	1.04 (0.90, 1.20)	0.98 (0.82, 1.17)
M4b. Availability	1.03 (0.98, 1.07)	1.01 (0.90, 1.13)	0.98 (0.95, 1.02)	0.97 (0.93, 1.01)	0.92 (0.81, 1.05)

Note: CI=Confidence Interval; Statistical significance level: *0.05, **0.01

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. In addition to the main effect models, the fully-adjusted association between tobacco retail availability and each outcome variable were stratified by levels of urbanity (M3a: urban centre, M3b: urban area) and levels of deprivation (M4a: less deprived, M4b: more deprived).

Appendix III. Longitudinal associations between tobacco retail availability, deprivation and smoking behaviours (men and women)

	Current smoking versus current non-smoking	Non-daily smoking versus current non-smoking	Daily smoking versus non- daily smoking	Quitting versus current smoking	Longer duration of abstinence versus current smoking
	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
M1a. Availability	1.02 (0.98, 1.05)	1.04 (0.99, 1.09)	1.02 (1.00, 1.05)	0.98 (0.96, 1.01)	0.95 (0.91, 1.01)
M1b. Deprivation	1.16 (1.02, 1.32)*	1.18 (0.99, 1.40)	1.02 (0.84, 1.25)	0.90 (0.79, 1.03)	0.79 (0.65, 0.97)*
M2a. Availability	1.02 (0.99, 1.05)	1.06 (1.01, 1.11)*	1.02 (1.00, 1.05)	1.02 (1.00, 1.05)*	0.95 (0.90, 1.01)
M2b. Deprivation	1.13 (1.07, 1.26)*	1.20 (0.99, 1.46)	1.04 (0.89, 1.23)	0.95 (0.83, 1.08)	0.80 (0.65, 0.99)*
M3a. Availability	1.04 (1.00, 1.08)*	1.06 (1.00, 1.12)*	1.01 (0.98, 1.04)	0.97 (0.93, 1.00)	0.89 (0.81, 0.99)*
M3b. Availability	0.94 (0.87, 1.01)	1.04 (0.91, 1.18)	1.09 (0.99, 1.20)	1.07 (0.97, 1.17)	1.02 (0.90, 1.16)
M4a. Availability	0.94 (0.86, 1.03)	1.05 (0.92, 1.19)	1.09 (0.94, 1.26)	1.08 (0.98, 1.20)	1.01 (0.90, 1.13)
M4b. Availability	1.02 (0.99, 1.06)	1.04 (0.98, 1.11)	1.02 (1.00, 1.05)*	0.98 (0.94, 1.01)	0.95 (0.88, 1.02)

Note: CI=Confidence Interval; Statistical significance level: *0.05, **0.01

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. In addition to the main effect models, the fully-adjusted association between tobacco retail availability and each outcome variable were stratified by levels of urbanity (M3a: urban centre, M3b: urban area) and levels of deprivation (M4a: less deprived, M4b: more deprived).

Appendix IV. The association between tobacco retail availability and smoking behaviours adjusted through wave indicator (men and women)

	Current smoking versus current non-smoking	Non-daily smoking versus current non-smoking	Daily smoking versus non- daily smoking	Quitting versus current smoking	Longer duration of abstinence versus current smoking
	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
M5a. Wave (unadjusted)					
Wave 3	Reference group	Reference group	Reference group	Reference group	Reference group
Wave 4	1.03 (0.90, 1.18)	1.14 (0.68, 1.94)	0.98 (0.60, 1.60)	1.44 (0.98, 2.10)	2.37 (1.17, 4.83)*
Wave 5	0.77 (0.68, 0.87)**	0.79 (0.47, 1.31)	0.87 (0.53, 1.42)	2.99 (1.96, 4.56)**	3.62 (1.62, 8.10)**
M5b. Wave (adjusted)					
Wave 3	Reference group	Reference group	Reference group	Reference group	Reference group
Wave 4	0.98 (0.81, 1.17)	1.12 (0.65, 1.93)	0.95 (0.56, 1.60)	1.31 (0.84, 2.03)	1.95 (1.04, 3.65)*
Wave 5	0.65 (0.53, 0.80)**	0.74 (0.40, 1.38)	0.96 (0.48, 1.72)	2.62 (1.64, 4.18)**	2.70 (1.40, 5.18)**

Note: CI = Confidence Interval; Statistical significance level: *0.05, **0.01

M5a only included wave as the explanatory variable for each outcome variable while tobacco retail availability and individual-level covariates were controlled in M5b.

Appendix V. Main effect cross-sectional models with all covariates (men only)

	Current smoking versus current non-smoking	Non-daily smoking versus current non-smoking	Daily smoking versus non-daily smoking	Quitting versus current smoking	Longer duration of abstinence versus current smoking
	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
M1a. Availability (unadjusted)	1.03 (1.00, 1.07)* P < 0.05	1.06 (0.99, 1.14) P > 0.05	1.01 (0.97, 1.04) P > 0.05	0.98 (0.94, 1.01) P > 0.05	0.92 (0.83, 1.02) P > 0.05
M1b. Deprivation (unadjusted)	1.23 (1.05, 1.43)** P < 0.05	1.40 (0.92, 2.12) P > 0.05	1.02 (0.79, 1.32) P > 0.05	0.86 (0.71, 1.04) P > 0.05	0.63 (0.46, 0.87)** P < 0.05
M2a. Availability (adjusted)	1.04 (1.00, 1.07)*	1.07 (0.96, 1.18)	1.01 (0.97, 1.04)	0.98 (0.94, 1.01)	0.93 (0.85, 1.02)
Age					
Age in years	1.12 (1.01, 1.24)*	1.12 (0.83, 1.50)	0.91 (0.75, 1.10)	1.22 (0.97, 1.54)	1.10 (0.81, 1.50)
Age squared	0.999 (0.998, 1.000)**	0.999 (0.996, 1.001)	1.001 (0.999, 1.003)	0.999 (0.997, 1.001)	0.999 (0.997, 1.002)
Levels of education					
Low	REF	REF	REF	REF	REF
Medium	0.93 (0.60, 1.42)	1.70 (0.45, 6.41)	1.21 (0.50, 2.90)	0.60 (0.34, 1.03)	0.55 (0.22, 1.38)
High	0.35 (0.17, 0.69)**	1.01 (0.14, 7.40)	2.51 (0.59, 10.77)	2.06 (0.87, 4.90)	3.78 (1.14, 12.52)*
NA	0.22 (0.01, 5.21)			5.86 (0.28, 121.60)	
Levels of household income per month, n(%)					
Low	REF	REF	REF	REF	REF
Medium low	1.90 (0.85, 4.26)	10.788 (0.51, 225.69)	1.62 (0.17, 15.10)	0.90 (0.26, 3.13)	0.68 (0.06, 8.11)
Medium high	2.19 (1.04, 4.60)*	40.11 (1.57, 1026.10)*	2.34 (0.29, 19.26)	1.10 (0.35, 3.45)	1.52 (0.18, 12.94)
High	1.68 (0.80, 3.53)	17.10 (0.71, 414.65)	1.67 (0.20, 14.28)	1.20 (0.37, 3.82)	1.19 (0.13, 10.75)
NA	1.374 (0.54, 3.49)	19.95 (0.60, 668.72)	2.51 (0.23, 27.63)	1.46 (0.36, 5.96)	3.38 (0.33, 34.78)
	P < 0.001	P > 0.05	P > 0.05	P > 0.05	P < 0.05
M2b. Deprivation (adjusted)	1.21 (1.03, 1.42)*	1.48 (0.85, 2.58)	1.03 (0.79, 1.34)	0.86 (0.70, 1.05)	0.68 (0.49, 0.93)*
Age					
Age in years	1.11 (1.01, 1.23)*	1.11 (0.83, 1.49)	0.91 (0.75, 1.10)	1.22 (0.97, 1.53)	1.11 (0.81, 1.51)
Age squared	0.999 (0.998, 1.000)*	0.999 (0.996, 1.001)	1.001 (0.999, 1.003)	0.999 (0.997, 1.001)	0.999 (0.997, 1.002)
Levels of education					
Low	REF	REF	REF	REF	REF
Medium	0.93 (0.61, 1.43)	1.79 (0.48, 6.70)	1.20 (0.50, 2.89)	0.60 (0.35, 1.04)	0.54 (0.22, 1.36)
High	0.37 (0.19, 0.74)*	1.15 (0.16, 8.56)	2.53 (0.59, 10.92)	1.92 (0.80, 4.60)	3.00 (0.90, 10.02)
NA	0.19 (0.01, 4.09)			6.53 (0.31, 135.53)	
Levels of household income per month, n(%)					
Low	REF	REF	REF	REF	REF
Medium low	1.91 (0.85, 4.25)	10.29 (0.50, 212.68)	1.62 (0.17, 15.10)	0.90 (0.26, 3.14)	0.64 (0.05, 7.61)
Medium high	2.14 (1.02, 4.49)*	37.37 (1.48, 941.55)*	2.33 (0.28, 19.13)	1.12 (0.36, 3.50)	1.57 (0.19, 13.28)
High	1.70 (0.81, 3.56)	16.15 (0.68, 383.48)	1.67 (0.20, 14.29)	1.19 (0.37, 3.80)	1.12 (0.12, 10.05)
NA	1.40 (0.55, 3.57)	20.41 (0.62, 671.47)	2.50 (0.23, 27.64)	1.43 (0.35, 5.86)	3.07 (0.30, 31.54)
	P < 0.001	P > 0.05	P > 0.05	P > 0.05	P < 0.05

Note: CI = Confidence Interval; Statistical significance level: *0.05, **0.01

Appendix VI. Main effect longitudinal models with all covariates (men only)

	Current smoking versus current non-smoking	Non-daily smoking versus current non-smoking	Daily smoking versus non-daily smoking	Quitting versus current smoking	Longer duration of abstinence versus current smoking
	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
M1a. Availability (unadjusted)	1.02 (0.99, 1.04) P > 0.05	1.05(1.00, 1.10) P > 0.05	1.03 (1.00, 1.05) P > 0.05	0.98 (0.96, 1.01) P > 0.05	0.94 (0.89, 0.99) P > 0.05
M1b. Deprivation (unadjusted)	1.16 (1.01, 1.33)* P < 0.05	1.18 (0.99, 1.41) P > 0.05	1.02 (0.84, 1.25) P > 0.05	0.91 (0.79, 1.04) P > 0.05	0.74 (0.62, 0.88)** P < 0.01
M2a. Availability (adjusted)	1.02 (0.98, 1.05)	1.06 (1.00, 1.12)*	1.02 (1.00, 1.05)	0.99 (0.96, 1.02)	0.95 (0.90, 1.01)
Age					
Age in years	1.17 (1.07, 1.28)**	1.45 (1.20, 1.75)**	1.26 (0.98, 1.61)	1.20 (0.93, 1.55)	1.30 (0.83, 2.06)
Age squared	0.998 (0.997, 0.999)**	0.996 (0.995, 0.998)**	0.998 (0.996, 1.000)	0.999 (0.997, 1.001)	0.998 (0.994, 1.002)
Levels of education					
Low	REF	REF	REF	REF	REF
Medium	0.77 (0.53, 1.12)	2.02 (0.89, 4.59)	2.08 (1.04, 4.18)*	0.79 (0.53, 1.17)	0.80 (0.38, 1.67)
High	0.42 (0.23, 0.75)*	3.30 (1.27, 8.59)*	6.36 (2.43, 16.64)**	1.49 (0.54, 4.07)	1.60 (0.45, 5.69)
NA	0.36 (0.04, 3.42)			6.67 (0.52, 85.29)	
Levels of household income per month, n(%)					
Low	REF	REF	REF	REF	REF
Medium low	0.94 (0.63, 1.42)	0.90 (0.45, 1.80)	0.99 (0.56, 1.76)	1.39 (0.82, 2.35)	2.13 (0.98, 4.63)
Medium high	1.16 (0.75, 1.81)	1.07 (0.41, 2.78)	0.78 (0.37, 1.65)	1.95 (1.01, 3.74)*	2.90 (0.96, 8.76)
High	0.79 (0.54, 1.16)	0.32 (0.17, 0.61)**	0.39 (0.18, 0.88)*	2.58 (1.2, 5.35)*	4.72 (1.52, 14.62)**
NA	0.84 (0.37, 1.91)	1.28 (0.42, 3.97)	1.63 (0.53, 4.97)	1.97 (0.646, 5.99)	4.77 (1.24, 18.24)*
	P < 0.01	P < 0.01	P < 0.01	P < 0.01	P < 0.01
M2b. Deprivation (adjusted)	1.13 (1.01, 1.26)*	1.20 (0.98, 1.47)	1.05 (0.89, 1.23)	0.96 (0.84, 1.10)	0.82 (0.66, 1.02)
Age					
Age in years	1.17 (1.07, 1.29)**	1.42 (1.19, 1.69)**	1.27 (0.99, 1.63)	1.20 (0.93, 1.55)	1.31 (0.83, 2.07)
Age squared	0.998 (0.997, 0.999)**	0.997 (0.995, 0.998)**	0.998 (0.996, 1.000)	0.999 (0.997, 1.001)	0.998 (0.994, 1.002)
Levels of education					
Low	REF	REF	REF	REF	REF
Medium	0.79 (0.53, 1.15)	1.92 (0.86, 4.28)	2.08 (1.04, 4.14)*	0.79 (0.53, 1.17)	0.79 (0.38, 1.66)
High	0.46 (0.26, 0.82)**	3.54 (1.34, 9.34)**	6.47 (2.56, 16.34)**	1.45 (0.51, 4.09)	1.41 (0.40, 4.96)
NA	0.30 (0.03, 3.03)			7.48 (0.56, 99.18)	
Levels of household income per month, n(%)					
Low	REF	REF	REF	REF	REF
Medium low	0.94 (0.63, 1.42)	0.92 (0.47, 1.81)	0.98 (0.56, 1.73)	1.39 (0.82, 2.35)	2.15 (0.96, 4.81)
Medium high	1.16 (0.74, 1.81)	1.05 (0.44, 2.52)	0.78 (0.37, 1.64)	1.95 (1.02, 3.74)*	2.96 (0.97, 9.05)
High	0.81 (0.55, 1.19)	0.34 (0.18, 0.66)**	0.39 (0.18, 0.87)*	2.58 (1.24, 5.37)*	4.69 (1.53, 14.39)**
NA	0.89 (0.40, 1.99)	1.45 (0.46, 4.59)	1.61 (0.52, 4.96)	1.95 (0.64, 5.95)	4.48 (1.17, 17.12)*
	P < 0.01	P < 0.01	P < 0.01	P < 0.01	P < 0.01

Note: CI = Confidence Interval; Statistical significance level: *0.05, **0.01

**Chapter 7 The potential impacts of spatial
restrictions on tobacco retail provision in China: a
simulation study in Shanghai**

7.1 Abstract

Objectives. Regulating tobacco retail availability provides promising new opportunities for effective tobacco control. This study simulates the potential impacts of introducing spatial restrictions on the availability of tobacco in Shanghai, the biggest mega-city in China with a highly developed tobacco retail market.

Methods. Twelve stakeholder-informed simulation scenarios under four major types of spatial restrictions were considered using tobacco retailer data across Shanghai in 2019 ($n = 19,413$). The percentage reduction in tobacco retail availability measured by population-weighted Kernel Density Estimation across neighbourhoods was used to assess the effectiveness of simulation scenarios in reducing tobacco retail availability, while impacts on social inequality in availability were estimated using the Kruskal-Wallis test and effect size estimation. All analyses were further stratified by 3 levels of urbanity to examine the geographical disparities in effectiveness and equity of the simulation scenarios.

Results. All simulation scenarios have the potential to reduce tobacco retail availability, with the percentage reduction ranging from 8.6% to 85.5%. Compared to the baseline, the effect size regarding the association between tobacco retail availability and neighbourhood deprivation quintiles suggests that the most effective scenario “500m-minimum spacing” increased the social inequality in availability ($p < 0.001$). Conversely, school buffer scenarios were both effective and equitable. Additionally, the effectiveness and the equity impact of scenarios varied by urbanity level.

Conclusion. Spatial restrictions offer potential new policy opportunities to address tobacco availability but may also increase social inequality in accessing tobacco. For effective tobacco control, policymakers should consider the overall and equity impacts of spatial restrictions when developing comprehensive tobacco retail regulations.

7.2 Introduction

Tobacco is the leading preventable cause of mortality and morbidity in China, accounting for over 1 million deaths^{1, 2} and USD 45.28 billion in medical costs in 2015.³ Proposed as a national strategy in 2016, *Healthy China 2030* sets an ambitious aim of reducing national-level smoking prevalence to 20% and reducing inequalities in health.^{4, 5} Although progress on tobacco control has been made in recent years, such as smoke-free legislation, there is a long way to go if China is to meet these ambitions and fulfil its commitment to the WHO Framework Convention on Tobacco Control (FCTC).

Among the most promising policy options for reducing the prevalence of smoking are interventions designed to limit the local availability of tobacco products. Previous research suggested that better access to tobacco products could promote smoking behaviours by reducing the cost of obtaining tobacco products, increasing brand awareness, and creating a competitive retail market.⁶ Increasing international empirical evidence suggests greater tobacco retail density is associated with greater consumption of tobacco,^{7, 8} a higher likelihood of smoking initiation or smoking,⁹⁻¹² and lower odds of cessation.^{10, 13, 14} Additionally, established evidence from western high-income countries (HICs) suggests that the distribution of tobacco retailers is socially patterned, with more tobacco retailers found in more deprived,^{15, 16} more urbanised,¹⁶ and high-minority neighbourhoods.¹⁷ These findings emphasise that regulating tobacco retail availability could be an important component of complete tobacco control policies, not only for public health but also for tobacco-related health inequalities.¹⁴

Given the strength of international evidence linking tobacco retail availability and tobacco-related outcomes, there is a great interest in interventions that regulate the availability and supply of tobacco.¹⁸ Four major types of spatial restrictions for regulating tobacco retail have been identified,¹⁸ including capping the number of retailers in an area; ban of tobacco sales in specific retailer types; school buffer exclusion zone; and minimum spacing. These spatial restrictions have been enforced using different thresholds in cities across the US, the UK, Canada, Australia, and some

European countries.¹⁸ Previous research from the US¹⁹⁻²⁵ and Scotland²⁶ suggests these spatial restrictions have the potential to reduce tobacco retail availability substantially, although the effectiveness of different spatial restrictions varies by type and geographical context.²⁵ Spatial restrictions also offer the potential to reduce tobacco-related inequalities, and while results are mixed, a small number of studies using simulation methods have evaluated the impacts of spatial restrictions on different social groups.²⁵⁻²⁹

To date, most work simulating the impacts of restrictions on the availability of tobacco has been limited to high-income countries (HICs), and there has been no work in China. In China, to sell tobacco products legally, all retailers are required to purchase tobacco retail licenses from local Tobacco Monopoly Bureaus (TMB). Among the requirements for tobacco retail licensing, spatial restrictions are designed and implemented at the local level under national-level guidelines. Therefore, spatial restrictions for tobacco retail vary across geographic areas (see Appendix I). Having been legislated nationally in 2021,³⁰ the school buffer exclusion zone is the most important and most widely used spatial restriction for tobacco retail with the aim of protecting adolescents from earlier smoking initiation.³¹ Tobacco products are not permitted to be sold around schools, with a varying radius ranging from 50m to 100m in different cities.³²⁻³⁶ Minimum spacing and capping have also been enforced in some cities of China with thresholds ranging from 40m³⁶ to 50m.^{32, 34} Although not as common as the other two types of spatial restrictions, capping is more widely used in the rural context of China.^{32, 33} Unlike the US, in China, tobacco products are not allowed to be sold in pharmacies, but there are no further restrictions on prohibiting tobacco sales in other retailer types, such as convenience stores, the marketing of tobacco products at these retailers may influence smoking initiation among adolescents who make frequent visits.³⁷

The effectiveness of spatial restrictions for tobacco retail availability reduction and the corresponding equity impacts may vary greatly by type of spatial restrictions and context.^{26, 28} The “SimSmoke” study has projected the impacts of tobacco control policies in China at the national level,³⁸ yet no local-level evidence with a retail focus has been provided. Simulation studies using real-world data could provide insights

into understanding the potential impacts of different restrictions on tobacco retail provision and equity.²⁶ The focus of the current study is Shanghai, the biggest megacity of China where city-wide availability of tobacco retailers is high, but with significant variations across levels of urbanity and neighbourhood deprivation. The large number of smokers,³⁹ the high availability of tobacco retailers, and the existing socio-spatial inequalities in tobacco retail availability make Shanghai an important context for examining the potential impacts of varying spatial restrictions. Therefore, using data across the Shanghai metropolitan area, we aim to simulate a variety of potential restrictions designed to reduce the availability of tobacco retailing. We consider the extent to which each stakeholder-informed scenario affects the availability of tobacco retailing compared to the baseline situation, as well as the impact on social inequalities in tobacco retail availability.

7.3 Methods

7.3.1 Baseline

The baseline scenario was constructed based on the distribution of tobacco retailers across Shanghai in May 2019. Tobacco retailer data were obtained through web-scraping Point of Interest data (POIs) from Baidu Online Map. After removing duplicates, cleaning, and validating POIs, a total of 19,413 POIs were identified as operating tobacco retailers and included in the analyses. Three major types of tobacco retailers were considered, including convenience stores ($n = 9,436$), supermarkets ($n = 5,319$), and tobacco-only outlets ($n = 3,658$). Considering roughly 90% of the students (age 6-18) are educated in public schools,⁴⁰ a list of the 1,483 registered public schools in Shanghai in 2019 was obtained from the official website of the Department of Education of the 16 districts of Shanghai,⁴¹⁻⁴³ and was geocoded using the names and addresses through the API of Baidu Online Map.

By the end of 2019, although a number of tobacco control policies such as smoke-free policies have been implemented in Shanghai, the only enforced spatial restrictions focusing on tobacco retail in the metropolitan area was the 50m-prohibiting distance for tobacco retailing from the main entrance of schools.

7.3.2 Neighbourhood deprivation

Based on the 2010 Chinese census at residential community-level (avg. population = 5,888) and following previous Chinese studies,^{44, 45} the neighbourhood deprivation index was constructed using an equal-weighting measure by summing up 4 indicators: (1) unemployment rate; (2) low-skilled worker 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 were tenants) after standardising. Neighbourhoods across Shanghai were then grouped into quintiles according to deprivation levels (1st quintile = least deprived, 5th quintile = most deprived).

7.3.3 Simulation scenarios

A series of simulation scenarios were constructed under 4 types of spatial restrictions:¹⁸ (1) capping the number of tobacco retailers; (2) banning sales in specific venues; (3) minimum spacing between retailers; and (4) school buffer exclusion zone. In order to inform our modelling strategy, we completed a key stakeholder survey to evaluate the perceived effectiveness and importance of the 4 types of spatial restrictions in reducing tobacco retail availability through an online questionnaire. Piloted with 2 key participants, the survey was eventually completed by 28 participants from China's public sector (53.6%), tobacco control association advocacy (39.3%), academia or research institute (25%), and the private sector (9.1%) via snowball sampling. The participants were asked to assess a range of detailed policy interventions, including their effectiveness, importance, and plausible thresholds for 4 types of spatial restrictions (see Appendix II). According to the responses from participants (see Appendix II), the most and the second-most plausible thresholds for each restriction type were selected to construct simulation scenarios. In addition to the insights from the stakeholder survey, our analytical approach was also informed by the established evidence, including previously enacted spatial restrictions on tobacco retailing in China and other countries, as well as prior simulation studies. Consequently, across the 4 types of spatial restrictions, a total of 12 simulation scenarios were completed. The simulation scenarios were constructed using a variety of spatial analysts in Arc GIS (i.e. "buffer" function) and R packages (i.e. "spatstat", "spThin"); the details and the rationale for constructing simulation scenarios are provided in Table 7.1.

7.3.4 Measuring tobacco retail availability

For each simulation scenario, the remaining tobacco retailers were mapped in ArcGIS using Kernel density estimation (KDE) analysis. KDE has advantages over other measures of availability because it is not constrained by administrative boundaries. The smoothed density of tobacco retailers of Shanghai was calculated by dividing the city of Shanghai into $100\text{m} \times 100\text{m}$ grids with an 800m-searching radius (10-min walking distance).¹⁵ Tobacco retailers close to the centre of the search window were assigned greater weights than those further away. In order to estimate tobacco retailer

density at the subcommunity level, the centroid of the area was overlaid on the KDE surface and the value of the corresponding cell was extracted. This value was then weighted by the total population of each subcommunity (sourced from the 2010 Chinese census of Shanghai) to represent the neighbourhood-level tobacco retail availability (count of tobacco retailers per km² per neighbourhood).

7.3.5 Analyses

For each simulation scenario, two sets of analyses were performed to evaluate the effects on tobacco retail availability reduction and inequality in tobacco retail availability across the city and by 3 levels of urbanity. The potential impact of spatial restrictions on availability reduction was measured as the median percentage reduction in population-weighted KDE per neighbourhood against the baseline due to the non-normal distribution of population-weighted KDE.

Descriptive statistics, the Kruskal-Wallis test, and effect size estimation were performed to examine the impact on equity. Given the non-normal distribution of population-weighted KDE, the distribution of tobacco retail availability by levels of deprivation was summarised by the median of population-weighted KDE. Further, a non-parametric rank-based test, the Kruskal-Wallis test, was performed to assess statistical differences in availability among levels of deprivation quintiles for each simulation scenario.⁴⁶ Finally, measured by epsilon squared (ε^2),⁴⁷ the effect size was utilised to evaluate whether the association between neighbourhood deprivation quintiles and availability was weakened or strengthened before and after the implementation of simulation scenarios. The effect size could reflect the strength of the relationship between variables and provide an estimation of the importance of this relationship.⁴⁷ The values of ε^2 ranged from 0 (no impact) to 1 (full impact).

The potential impacts of spatial restrictions may differ across diverse environment.²⁸ Therefore, these two sets of analyses were further stratified by 3 levels of urbanity (urban centre vs urban area vs suburb), based on the categorisation from previous research in Shanghai.⁴⁸ Across Shanghai, the more urbanised areas are associated with greater economic activity and better access to urban infrastructure, with the urbanity level decreasing from the urban centre to the urban area and to the suburb.⁴⁹ All

statistical analyses were performed in the R environment, while the spatial analysis was conducted in R and ArcGIS 10.8.1.

Table 7.1 Constructing simulation scenarios

Types	Definition	Thresholds	Description	Rationale	Construction
Baseline	Prohibit tobacco sales within 50m-distance of the main entrance of schools.	-	-	-	Real-distribution of tobacco retailers and public schools of Shanghai, geocoded and mapped in ArcGIS.
Capping ("Cap")	A ceiling on the number of retailers permitted to sell tobacco within a specified geographic area.	Cap-90%	Reduce the number of tobacco retailers to 90% of the baseline.	The 2 nd most plausible threshold, selected by stakeholders (14.3%).	To explore statistical uncertainty, using "spatstat" of R, tobacco retailers were randomly removed 10 times for each scenario, leaving the subsets with the maximum count of tobacco retailers.
		Cap-80%	Reduce the number of tobacco retailers to 80% of the baseline.	The most plausible threshold, selected by stakeholders (17.9%).	
		Cap-50%	Reduce the number of tobacco retailers to 50% of the baseline.	Established evidence from other countries. ^{28, 50, 51}	
Ban of sales ("Ban")	Prohibiting tobacco sales in specific venues.	Convenience	Ban tobacco sales in convenience stores.	The most plausible threshold, selected by stakeholders (21.4%).	Using ArcGIS 10.8.1, the corresponding retailer type of tobacco retailers in the baseline was removed, respectively.
		Supermarket	Ban tobacco sales in supermarkets.	Established evidence from other countries. ²⁶	
		Tobacco-only	Restrict tobacco sales to tobacco-only outlets.	The 2 nd most plausible threshold, selected by stakeholders (14.3%).	
Minimum spacing ("Spacing")	Requiring a minimum distance between two neighbouring tobacco retailers.	Space-150m	A 150m-minimum spacing between any neighbouring tobacco retailers.	Established evidence from other countries. ^{52, 53}	To explore statistical uncertainty, using "spThin" of R, tobacco retailers were randomly removed 10 times for each scenario, leaving the subsets with the maximum count of tobacco retailers.
		Space-200m	A 200m-minimum spacing between any neighbouring tobacco retailers.	The 2 nd most plausible threshold, selected by stakeholders (14.3%).	
		Space-500m	A 500m-minimum spacing between any neighbouring tobacco retailers.	The most plausible threshold, selected by stakeholders (21.4%).	
School buffer exclusion zone ("Buffer")	Requiring a minimum distance to be outside of schools for tobacco retail.	Buffer-200m	A 200m-radius prohibiting zone for tobacco retail around the main entrance of schools.	The most plausible threshold, selected by stakeholders (25%).	Through ArcGIS 10.8.1, buffers at multiple radiuses were created around the main entrances of public schools. Tobacco retailers that fell within the buffers were removed for each threshold.
		Buffer-400m	A 400m-radius prohibiting zone for tobacco retail around the main entrance of schools.	A plausible 5-min walking distance.	
		Buffer-500m	A 500m-radius prohibiting zone for tobacco retail around the main entrance of schools.	The 2 nd most plausible threshold, selected by stakeholders (14.3%).	

7.4 Results

Figure 7.1 presents the total number of tobacco retailers under each simulation scenario and the percentage reduction against the baseline across the city. As anticipated, stricter restrictions would result in fewer tobacco retailers for each restriction type. Simulation scenarios could reduce 9.54% (cap-90%) to 81.16% (tobacco-only) of the total count of tobacco retailers compared to the baseline. The reduction rate by the count of tobacco retailers differed by urbanity level. The reduction rate of most simulation scenarios decreased from more urbanised areas (9.96%-84.25%) to less urbanised areas (9.31% -52.99%) (Figure 1, columns 2-4), while a reversed pattern was found for “tobacco-only” and “supermarket”.

7.4.1 Tobacco retail availability reduction

In order to reflect the impacts of simulation scenarios on availability reduction, Figure 7.2 displays the median availability under each simulation scenario and the corresponding percentage reduction against the baseline. As expected, stricter restrictions were associated with greater reduction rates for each type of spatial restriction. The median tobacco retail availability was 9.50 tobacco retailers per km² for each neighbourhood at the baseline, while the overall median availability of the simulation scenarios ranged from 1.42 (spacing-500 m) to 8.53 (cap-90%). Across the city, “spacing-500 m” was the most effective measure for availability reduction, with a percentage reduction of 85.45%, followed by “buffer-500 m” (68.1%). On the other hand, the most limited reduction rate was found for “cap-90%” (8.6%).

Tobacco retail availability reduction varied by urbanity level. As presented in columns 2-4 of Figure 7.2, “spacing-500 m” had the largest impact on availability reduction in the urban centre (90.71%) and the urban area (83.37%), while the greatest reduction rate was found for “tobacco-only” (85.06%) in the suburb. Likewise, the availability reduction rate for each simulation scenario varied across levels of urbanity (Figure 7.2). The availability reduction rate of “buffer-500 m” decreased from the urban centre (92.35%), to the urban area (79.44%), and to the suburb (26.51%), while a reverse pattern was found for “tobacco-only”.

Figure 7.1 The reduction rate by count of tobacco retailers across the city and by urbanity level

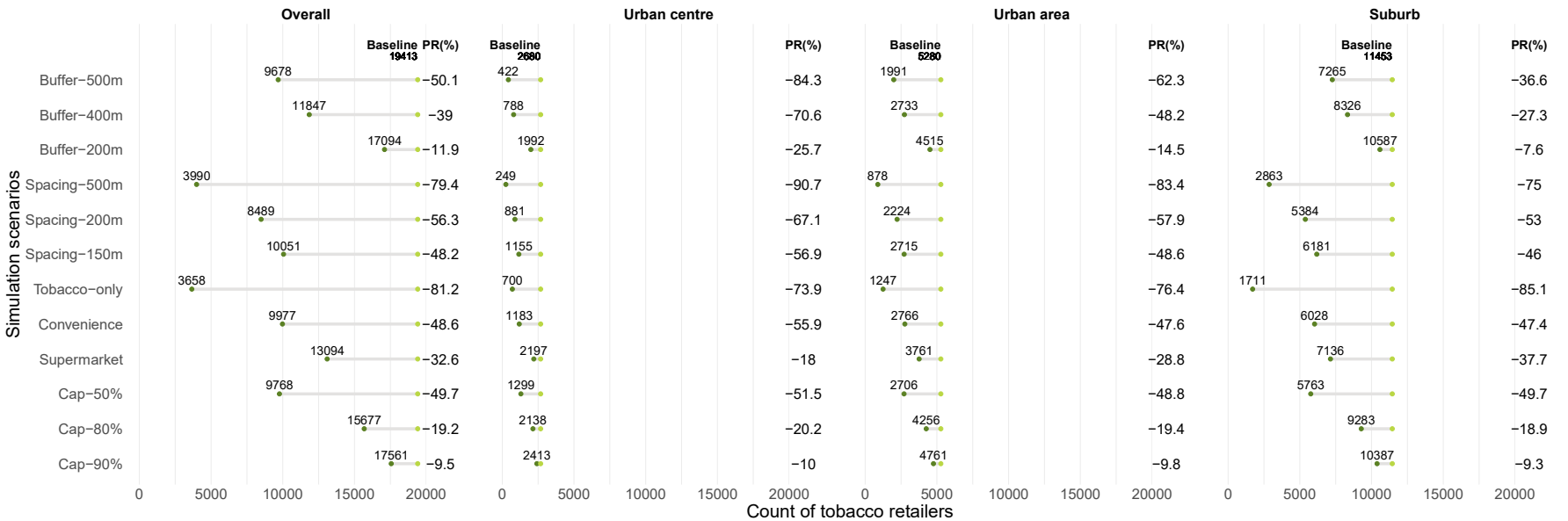
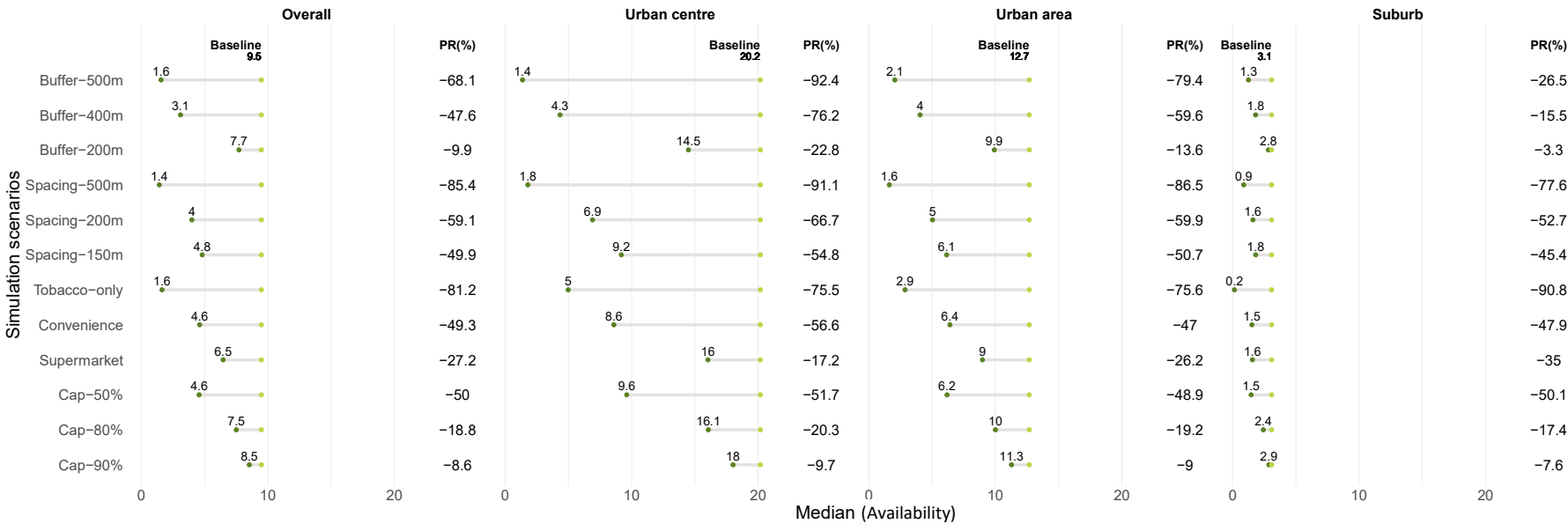


Figure 7.2 Tobacco retail availability reduction across the city and by urbanity level



7.4.2 Equity impact

To evaluate the equity impact of simulation scenarios, Table 7.2 provides a summary of the median tobacco retail availability of each deprivation quintile, the results of the Kruskal-Wallis test and effect size estimation before and after implementing simulation scenarios. Aligned with the baseline situation across the city, most simulation scenarios had the greatest availability in Q2 (less deprived) and the most limited availability in Q5 (the most deprived). However, “buffer-400 m” and “buffer-500 m” had the greatest availability in Q1 (the least deprived) and the smallest availability in Q4 (more deprived). The Kruskal-Wallis test suggested that neighbourhood deprivation quintiles had significant impacts on availability before and after the implementation of simulation scenarios ($p < 0.05$), but the magnitude of impacts varied by scenario. Reflecting the magnitude of the impact of neighbourhood deprivation on tobacco retail availability, the effect size ranged from 0.0331 (“buffer-500 m”, weak impact) to 0.1460 (“space-500 m”, relatively strong impact). Compared with the baseline ($\varepsilon^2 = 0.1127$, moderate), there were five simulation scenarios found with increased values of effect size. Notably, minimum spacing scenarios were among the most inequitable scenarios (0.1291-0.1460, moderate to relatively strong impact), while school buffer scenarios and capping scenarios had reduced values of effect size as compared to the baseline.

Likewise, the association between tobacco retail availability and neighbourhood deprivation quintiles varied greatly across levels of urbanity (Table 7.2). Although the effect size of the baseline decreased from urban centre neighbourhoods to suburban neighbourhoods and to urban area neighbourhoods, not all simulation scenarios followed the same pattern. Across the city, “spacing-500 m” was the most inequitable scenario with the greatest effect size. However, it became the most equitable scenario in urban centre neighbourhoods ($\varepsilon^2 = 0.0105$, weak impact).

In addition to the varying impacts of neighbourhood deprivation on tobacco retail availability in different simulation scenarios, the distribution of the reduction rate of availability by neighbourhood deprivation quintiles varied by restriction types. As shown in column 1 of Figure 7.3, for the city as a whole, tobacco retail availability

reduction differed by neighbourhood deprivation quintiles except for “capping”, whose reduction rate remained constant across quintiles. Among the other 3 types of spatial restrictions, school buffer scenarios had the greatest reduction rate in Q2 and the smallest in Q5. The reduction rates for minimum spacing scenarios and ban of sales scenarios differed by levels of deprivation, but not significantly enough. Figure 7.3 (columns 2-4) presents the variation in the distribution of availability reduction by neighbourhood deprivation quintile across urbanity levels. However, the spatial difference was not significant enough for most restriction types, except for scenarios regarding “buffer”.

Table 7.2 Tobacco retail availability by neighbourhood deprivation quintiles across the city and by urbanity level

Scenarios	Q1 (least deprived)	Q2	Q3	Q4	Q5 (most deprived)	Chi-squared	p-values	Effect size
Across the city								
Spacing-500m	1.65	1.68	1.40	1.06	0.98	793.10	0.00	0.1460
Spacing-200m	4.97	5.24	4.08	2.58	1.77	748.11	0.00	0.1378
Spacing-150m	6.07	6.55	4.93	2.71	2.00	701.05	0.00	0.1291
Tobacco-only	2.71	3.03	1.74	0.57	0.27	663.33	0.00	0.1221
Supermarket	6.02	10.08	7.16	2.76	1.76	622.53	0.00	0.1146
Baseline	12.19	13.67	10.15	5.04	3.34	611.80	0.00	0.1127
Cap-90%	10.73	12.41	9.14	4.55	2.98	605.08	0.00	0.1114
Buffer-200m	10.06	10.87	8.26	4.22	3.12	599.35	0.00	0.1104
Convenience	8.78	6.82	4.79	2.63	1.83	595.46	0.00	0.1096
Cap-80%	9.69	11.11	8.04	3.92	2.73	592.04	0.00	0.1090
Cap-50%	5.95	6.83	5.02	2.31	1.67	589.57	0.00	0.1086
Buffer-400m	4.69	3.92	2.64	1.71	2.64	371.86	0.00	0.0685
Buffer-500m	2.50	1.74	0.94	0.94	1.66	179.69	0.00	0.0331
Urban centre								
Supermarket	12.37	14.62	16.13	20.20	27.90	183.68	0.00	0.1919
Cap-90%	13.75	17.42	17.93	21.12	28.47	170.93	0.00	0.1786
Baseline	15.67	19.61	20.38	23.53	31.29	168.79	0.00	0.1764
Cap-80%	12.25	15.51	16.43	18.61	24.20	155.63	0.00	0.1626
Cap-50%	7.57	9.39	10.08	11.48	14.86	138.62	0.00	0.1449
Spacing-150m	8.01	8.94	9.19	10.62	10.82	108.67	0.00	0.1136
Buffer-200m	11.92	14.22	14.68	16.28	19.75	102.56	0.00	0.1072
Tobacco-only	4.01	4.74	4.86	6.60	7.52	102.46	0.00	0.1071
Convenience	7.06	8.33	8.96	10.27	11.19	89.585	0.00	0.0936
Spacing-200m	6.30	6.90	6.84	7.68	7.57	87.263	0.00	0.0912
Buffer-400m	4.07	3.89	4.39	4.11	5.39	18.265	0.00	0.0191
Buffer-500m	1.58	0.94	1.38	1.27	1.95	13.273	0.01	0.0139
Spacing-500m	1.74	1.86	1.82	1.76	1.84	10.052	0.04	0.0105
Urban area								
Spacing-200m	5.09	5.22	5.47	4.81	1.96	187.67	0.00	0.1066
Supermarket	8.75	9.72	10.13	9.01	2.31	186.45	0.00	0.1059
Baseline	12.51	13.26	13.98	12.33	3.9	182.00	0.00	0.1034
Convenience	6.45	6.88	7.64	6.04	2.15	181.53	0.00	0.1031
Spacing-150m	6.11	6.46	6.54	5.86	2.43	180.34	0.00	0.1024
Cap-90%	11.17	11.88	12.67	11.53	3.58	178.69	0.00	0.1015
Tobacco-only	2.90	3.13	3.69	2.73	0.54	176.70	0.00	0.1003
Cap-80%	10.03	10.5	11.12	9.69	3.26	176.04	0.00	0.1000
Spacing-500m	1.68	1.71	1.62	1.58	1.08	169.25	0.00	0.0961
Cap-50%	6.09	6.79	7.47	6.20	1.74	168.88	0.00	0.0959
Buffer-200m	10.03	10.18	10.96	9.98	3.84	163.68	0.00	0.0930
Buffer-400m	5.05	3.83	3.83	4.22	2.51	57.531	0.00	0.0327
Buffer-500m	2.51	1.83	1.62	2.30	1.97	22.644	0.00	0.0129
Suburb								
Spacing-200m	3.79	4.34	0.49	0.79	1.41	443.17	0.00	0.1635
Spacing-150m	4.33	5.14	0.53	0.88	1.57	422.45	0.00	0.1558
Baseline	8.31	11.14	0.85	1.35	2.56	395.19	0.00	0.1458
Cap-90%	7.50	9.96	0.75	1.18	2.23	387.27	0.00	0.1429
Supermarket	5.35	7.79	0.42	0.70	1.19	380.50	0.00	0.1404
Cap-80%	6.58	8.94	0.67	1.00	2.03	375.28	0.00	0.1384
Tobacco-only	1.73	1.73	0.00	0.00	0.56	375.19	0.00	0.1384
Buffer-200m	7.54	9.39	0.77	1.29	2.27	374.93	0.00	0.1383
Spacing-500m	1.44	1.48	0.40	0.53	0.83	373.23	0.00	0.1377
Cap-50%	4.25	5.24	0.42	0.69	1.19	369.60	0.00	0.1363
Convenience	4.51	5.25	0.44	0.67	1.28	341.71	0.00	0.1260
Buffer-400m	4.81	4.22	0.61	0.91	1.86	286.33	0.00	0.1056
Buffer-500m	3.49	2.18	0.43	0.69	1.55	217.75	0.00	0.0803

Note on effect size⁵⁴

0 < ε^2 < 0.01: negligible impact;

0.01 < ε^2 < 0.04 weak impact;

0.04 < ε^2 < 0.16 moderate impact;

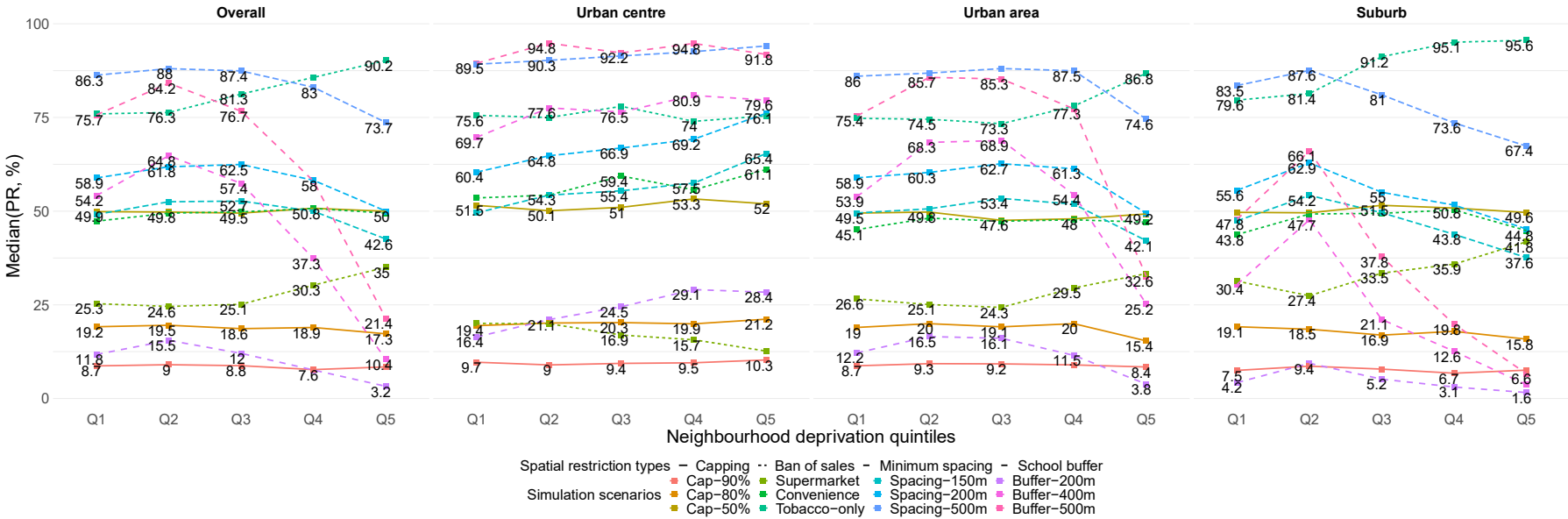
0.16 < ε^2 < 0.36 relatively strong impact;

0.36 < ε^2 < 0.64 strong impact;

0.64 < ε^2 < 1 very strong impact.

Scenarios are ranked by effect size, from the highest to the lowest.

Figure 7.3 Tobacco retail availability reduction by deprivation quintile across the city and urbanity level



7.5 Discussion

7.5.1 Summary of findings

Using retailer data from a megacity in China, our study simulated the potential impacts of a range of plausible simulation scenarios that aimed to reduce tobacco retail availability. Our simulations revealed that all restriction types would lead to substantial reductions in tobacco retail availability, but not all restrictions would reduce social inequality in tobacco retail availability. Specifically, “spacing-500 m” was the most effective restriction for availability reduction, but it greatly increased the social inequality in availability as compared to the baseline, while “buffer-500 m” was the second most effective restriction for availability reduction, and it was also the most equitable restriction which was found to have the weakest impact of neighbourhood deprivation quintiles on tobacco retail availability. Furthermore, the context, here the urbanity levels and the deprivation quintiles, played an important role in reshaping the local tobacco retail environment. The potential impacts of different spatial restrictions vary greatly by levels of urbanity and quintiles of deprivation.

7.5.2 Interpretations of key findings

Our findings demonstrate that spatial restrictions aimed at regulating tobacco retail have the capability of reducing availability and inequality. However, consistent with prior findings from Scotland,²⁶ the most effective spatial restriction for availability reduction could also increase inequalities. “Spacing-500 m” was capable of reducing the greatest availability across the city of Shanghai, but it also increased the social inequality in availability greatly. In Scotland, restricting tobacco sales to liquor stores or pharmacies increased inequality in availability, but they were also among the scenarios with the greatest availability reduction.²⁶ Contemporary health intervention strategies normally share the same aims, which include promoting overall health and reducing inequalities,⁵⁵ but both aims may not be achieved simultaneously, as we have found in our simulation study. Therefore, when enacting effective tobacco control interventions at the local level, policymakers may need to decide the priority between availability reduction and inequality reduction based on the local context as well as the objectives of the intervention.

Notably, although minimum spacing scenarios might not be able to achieve the aim of reducing availability and inequality simultaneously, school buffer scenarios appeared to have a considerably good performance in reducing both tobacco retail availability and inequality in the metropolitan area of Shanghai. As the first spatial restriction aimed at reducing tobacco retail exposure in China that has been legislated at the national level, our finding suggests school buffer restrictions can not only protect the underage from earlier smoking initiation, but also have the potential to reduce retail exposure to the full population equitably. This finding aligns with the opinions from key stakeholders (see Appendix II) that school buffer exclusion zone is the most important and most effective restriction type for regulating tobacco retail, which also supports the national level strategy of tobacco control.

In our study, the impacts of spatial restrictions differed by urbanity and deprivation level, which confirms the findings of Luke et al. (2017), who demonstrated that the impacts of policies or spatial restrictions are context-dependent and vary depending on the baseline.²⁸ Using “spacing-500 m” as an example, although it is the restriction that reduced the greatest availability and had the greatest level of inequality across the city, it became the most effective restriction for reducing tobacco retail availability and the most equitable scenario in urban centre neighbourhoods. While it might be related to school distribution, “buffer” scenarios could reduce a greater level of availability in less deprived neighbourhoods, but their effectiveness was greatly reduced in the most deprived neighbourhoods. Although the local-level is normally the smallest scale for policy enactment, we suggest that policymakers should have an awareness of the potential socio-spatial differentiation of the policy impacts.

Policy interest in spatial restrictions on tobacco retailing extends to other countries including states of the US,⁵⁶ Canada,⁵⁷ Australia,⁵⁸ and New Zealand,⁵⁹ as well as a number of European countries, such as Finland.⁶⁰ Although recommended by the WHO as an effective tobacco control strategy,⁶¹ tobacco retail licensing systems are not common across the world and have often lacked political support, likely due to opposition by tobacco retailer organisations supported by the tobacco industry.⁶⁰ As a country with a distinct policy environment for tobacco control, there is a long history of the established tobacco retail licensing system in China, which could be traced back

to the 1950s. However, in recent years, as a potential instrument of tobacco control by regulating retail outlets, local tobacco licensing requirements have not been fully implemented in China, likely due to the tobacco industry's close involvement in the tobacco control policymaking system, as well as the government's ambiguous attitudes towards the tobacco economy.⁶² However, as the importance of tobacco control measures gains recognition in China, policymakers should increasingly emboldened in identifying effective tobacco control initiatives, such as a more comprehensive tobacco licensing system with stricter spatial restrictions for regulating tobacco retail.

7.5.3 Limitations

This study has some limitations. First, although we used real-world data in Shanghai to simulate the potential impacts of different spatial restrictions on reducing tobacco retail availability, this study assumed that no licenses would be issued to new tobacco retailers. In reality, the tobacco environment is a dynamic system with new licenses for tobacco retail being issued and restrictions in one area likely to encourage new retailers in other areas. Second, illicit tobacco retailers were not considered due to the unavailability of robust data. However, illicit tobacco retail may not make a major contribution to the baseline considering the sharp decline in illicit tobacco consumption in China due to the increasing affordability of tobacco products in China,⁶³ especially in megacities like Shanghai. Third, the established spatial restrictions for minimum spacing in China normally require a minimum distance between two neighbouring tobacco retailers along the street. However, due to the limited capability of the R package, we cannot simulate minimum spacing scenarios along road networks. What is more, our study does not simulate the impacts of spatial restrictions on smoking and purchasing behaviours since there is a lack of individual smoking data covering the city of Shanghai. Therefore, we cannot estimate how different spatial restrictions would affect smoking and tobacco purchasing or identify the threshold effect of reducing the availability of tobacco retailers on smoking and purchase behaviours. Nevertheless, our study provides important insights into the effectiveness of reducing tobacco retail availability and socioeconomic inequality in availability at the local level, with the intention of contributing to a comprehensive tobacco control plan in the context of Chinese megacities. Future work may consider

using some more complex models, such as agent-based models, to simulate the dynamic retail market along the road network, considering the stochasticity of individual smoking and purchase behaviour, to provide a more realistic simulation of the plausible impacts of spatial restrictions for regulating tobacco retail.

7.6 Conclusion

This is the first study that simulates the impacts of local-level spatial restrictions aimed at reducing tobacco retail availability in the Chinese context. Our study uses a case study of Shanghai to address the potential of spatial restrictions in reshaping the local tobacco retail environment in China, particularly the possibility that spatial restrictions might not reduce availability for different social groups equally. Therefore, our study demonstrates the importance of ensuring tobacco availability measures not only reduce overall availability but also ensure policy implementation does not result in more inequitable availability and health outcomes.

7.7 References

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7.8 Supplementary Materials

Appendix I. Thresholds of spatial restrictions in different cities of China

City	School buffer exclusion zone	Minimum spacing	Capping	Ban of sales
Beijing	100m	50m	No more than 7 tobacco retailers in each administrative village	-
Changsha	100m	-	1 tobacco retailer for every 50 households	-
Hangzhou	100m	50m	-	-
Guangzhou	50m	-	-	-
Chongqing	50m	40m	-	-
Shanghai	50m	-	-	-

Appendix II. Online questionnaire and responses

Q1. How effectively do the following interventions could act on tobacco retail density reduction?

	0	1	2	3	4	5	6	7	8	9	10	Mean score
Capping	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	7.43
Ban of sales	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	7.89
Minimum spacing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	6.25
School buffer exclusion zone	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	8.46

Q2. Please rate the importance of the following interventions that could act on tobacco retail density reduction.

	Not at all important	Not so important	Somewhat important	Very important	Extremely important
Capping	1 (3.57%)	3 (10.71%)	4 (14.29%)	11 (39.29%)	9 (32.14%)
Ban of sales	0 (0%)	2 (7.14%)	3 (10.71%)	11 (39.29%)	12 (42.86%)
Minimum spacing	2 (7.14%)	4 (14.29%)	8 (28.57%)	9 (32.14%)	5 (17.86%)
School buffer exclusion zone	1 (3.57%)	1 (3.57%)	2 (7.14%)	5 (17.86%)	19 (67.86%)

Q3. In the context of Shanghai, China, please indicate the most plausible threshold that could be enforced in the future:

Options	The most plausible threshold	The second most plausible threshold
Capping_____.	80% of the baseline 5 (17.86%)	90% of the baseline 4 (14.29%)
Ban of sales_____.	Ban of sales in convenience store 6 (21.43%)	Restrict sales to tobacco-only outlets 4 (14.29%)
Minimum spacing_____.	500m 6 (21.43%)	200m 4 (14.29%)
School buffer exclusion zone_____.	200m 7 (25%)	500m 4 (14.29%)

Q4. Do you think if there is any other spatial restriction that could be effectively imposed on tobacco retail density reduction in the context of Shanghai, China, please indicate_____.

Q5. Please indicate the type of your organisation that you represent?

Options	Responses
Academia	7 (25%)
Tobacco control advocacy/ organisation	11 (39.29%)
Public sector	15 (53.57%)
Private sector	2 (7.14%)
Other, please indicate _____.	0 (%)

Chapter 8 Conclusions

This concluding chapter brings together four empirical chapters (Chapters 4-7). First, an overview of the key findings of each empirical chapter was provided. Furthermore, the contributions were discussed by synthesising the findings of the empirical chapters with the established evidence, followed by a discussion of the limitations of the empirical chapters and future directions for future research. Finally, the chapter concluded with the policy implications of all four empirical chapters.

8.1 Summary of key findings

The current thesis aims to investigate the socio-spatial patterning of tobacco retail and to examine how neighbourhood socio-commercial environments affect smoking behaviours as well as how plausible spatial restrictions aimed at reducing tobacco retail availability reshape the tobacco retail environment in megacities of China, using the case of Shanghai. To address the overall aim, four research questions were answered as follows.

Study 1 (Chapter 4). Does the availability of tobacco retailing vary across different levels of neighbourhood deprivation and urbanity? Does this association vary by the type of tobacco retailer?

Key findings. Neighbourhood-level tobacco retail availability differed by levels of neighbourhood deprivation, with the greatest availability in neighbourhoods with medium-level deprivation, and the most limited availability in the most deprived neighbourhoods. After stratifying the neighbourhoods by levels of urbanity, a social gradient in tobacco retail was found in urban centre neighbourhoods, while there was a slight increase in tobacco retail availability in the more deprived neighbourhoods in suburb. Among the types of tobacco retailers, convenience stores had the greatest availability; the availability of tobacco-only outlets was the most limited. However, tobacco-only outlets were more strongly associated with levels of neighbourhood deprivation.

Study 2 (Chapter 5). What is the retail distribution of tobacco retailers around public schools of Shanghai? Whether and to what extent do tobacco retailers cluster around

public schools? To what extent have tobacco retailers complied with spatial restrictions for regulating tobacco retail that prohibit tobacco sales around school areas?

Key findings. The overall availability of tobacco retailers within walking distances of public schools was high. Specifically, 79.2% and 95.8% of public schools in Shanghai were in the vicinity of tobacco retailers within 400 m and 800 m buffers around the main entrance, respectively. In turn, 29.4% and 60.1% of tobacco retailers were allocated within 400 m and 800 m buffers around the main entrances of public schools; the medians of tobacco retailers were 3 (400 m) and 15 (800 m), respectively. The spatial cluster analysis suggested there was a significant clustering of tobacco retailers around public schools in Shanghai. Most tobacco retailers were compliant with the spatial restriction on prohibiting tobacco retail around schools within 50 m of the main entrance, while 5.9% of public schools were exposed to non-compliant tobacco retailers.

Study 3 (Chapter 6). Are neighbourhood deprivation and tobacco retail availability associated with smoking behaviours? Do relationships between tobacco retail availability and smoking behaviours vary by levels of urbanity and neighbourhood deprivation?

Key findings. Cross-sectionally, males living in neighbourhoods characterised by high tobacco retail availability and high-level deprivation were more likely to become current smokers. However, a longer duration of smoking abstinence was only found to be associated with lower neighbourhood deprivation. In urban centre neighbourhoods, males living in neighbourhoods with higher tobacco retail availability were more likely to smoke and less likely to quit. Higher tobacco retail availability was associated with greater odds of daily smoking in urban area neighbourhoods and less deprived neighbourhoods.

Longitudinally, there was a statistically significant unadjusted association between higher tobacco retail availability and reduced odds of a longer duration of abstinence; higher tobacco retail availability was found to be associated with non-daily smoking after controlling for individual covariates; males living in more deprived neighbourhoods were more likely to become current smokers and have a longer

duration of smoking abstinence (unadjusted). Within urban centre neighbourhoods, higher tobacco retail availability was associated with increased odds of non-daily smoking and reduced odds of a longer duration of smoking abstinence. Within more deprived neighbourhoods, greater tobacco retail availability was associated with increased odds of daily smoking.

Study 4 (Chapter 7). What is the effectiveness of different spatial restrictions on tobacco retail availability reductions? Whether spatial restrictions aimed at reducing tobacco retail availability would increase the social inequality in tobacco retail availability?

Key findings. Simulations revealed all spatial restrictions aimed at regulating tobacco retail are capable of reducing tobacco retail availability considerably, but not all of them would reduce social inequality in tobacco retail availability. Specifically, requiring a minimum spacing of 500 m between two neighbouring tobacco retailers had the greatest effectiveness in reducing tobacco retail availability. However, it greatly increased social inequality in tobacco retail availability as compared to the baseline scenario. The school buffer exclusion zone at 500 m was the second most effective scenario for reducing tobacco retail availability, but it was the most equitable simulation that reduced the social inequality in tobacco retail availability simultaneously. Additionally, simulations also revealed that the impacts of spatial restrictions may vary by urbanity level and neighbourhood deprivation level.

8.2 Contribution to theories

This section illustrates the contribution of this thesis to the existing literature in several ways by bringing findings from all chapters together and embedding them into the literature, such as the socio-spatial disparities in tobacco retail availability in residential and around schools; how neighbourhood deprivation and tobacco retail availability affect smoking behaviours; as well as how place-based spatial restrictions contribute to tobacco retail availability reduction.

8.2.1 Socio-spatial disparities in tobacco retail availability

First, this thesis extends our knowledge of the socio-spatial patterning of tobacco retail within neighbourhoods and around schools by providing evidence from Shanghai, which is the biggest and most developed megacity of China with a ubiquitous availability of tobacco retailers across the metropolitan area. Aligned with previous findings from high-income countries (HICs), tobacco retailers were disproportionately distributed in more urbanised areas.^{1,2} In Shanghai, tobacco retail availability within neighbourhoods (Study 1) and around public schools (Study 2) decreased from more urbanised to less urbanised areas of the metropolitan area.

Established evidence from the HICS suggests a social gradient in tobacco retailing that tobacco retailers are more clustered within more deprived neighbourhoods^{1,3-11} and around schools with a majority of low-income or minority students.¹² Study 1 revealed a significant non-linear association between tobacco retail availability and neighbourhood deprivation quintiles in Shanghai, with the highest neighbourhood tobacco retail availability in medium deprived neighbourhoods. Similar to what has been documented in Scotland, the most deprived neighbourhoods of Shanghai had the most limited availability of tobacco retailers.² Plausible reasons have been covered in section 4.5.2. The unique social patterning of tobacco retail availability in Chinese megacity could also be related to the rural-to-urban transition driven by the transition economy and rapid urbanisation among those most deprived neighbourhoods. Further examining the disparities in tobacco retail availability by levels of school deprivation in Study 2, unlike previous findings from HICs, no significant disparities could be found in Shanghai.

In contrast to findings of previous Chinese studies, Study 1 suggested neighbourhood-level tobacco retail availability (i.e. population-weighted KDE) was statistically differed by levels of neighbourhood deprivation in Shanghai, while Wang (2015) reported tobacco retail availability (i.e. count of tobacco retailers within neighbourhoods) had a positive but non-significant association with neighbourhood-level socioeconomic characteristics (i.e. neighbourhood-level average property price) in Changsha.¹³ The inconsistency could be attributed to the sample size, sampling strategy, and the measurement of tobacco retail availability, which will be further addressed in section 8.3.1.

Even though the underage are not allowed to purchase tobacco products legitimately, evidence from high-income countries suggests the tobacco industry tries to target the underage as replacement smokers^{14,15} through the display, advertising, and promotion of tobacco products within points of sale.¹⁶⁻¹⁹ Research in Australia reported a greater availability of tobacco retailers around schools than the state median.²⁰ A number of research has investigated the tobacco retail environment around schools in different cities of China. Broadly agreed with the general trend of previous findings in China, Study 2 (Chapter 5) suggested the overall high availability of tobacco retailers around public schools. Further using bivariate and multivariate spatial cluster analysis to examine the retail patterning of tobacco retailer around public schools, Study 2 is the first Chinese study determined the clustering pattern of tobacco retailers towards public schools.

Similar to what has been documented in HICs and other cities of China,^{21,22} in Shanghai, convenience stores were also found with the highest prevalence as compared to supermarkets and tobacco-only outlets. In addition to this, Study 1 also extends the established evidence by demonstrating a stronger association between tobacco retail availability in tobacco-only outlets and neighbourhood deprivation. Further, in Study 2, convenience stores were also the most available retailer type around public schools, while a greater proportion of tobacco-only outlets were allocated around public schools with higher degrees of clustering. These findings point to the underlying dual roles of China's local TBMs in regulating tobacco retail and promoting tobacco sales, suggesting local TBMs may have a preference for convenience chain stores and

tobacco-only outlets in the process of tobacco retail licensing, due to the widespread availability of convenience stores in facilitating tobacco advertising and marketing at point-of-sales, exploiting the differential advertising and marketing behaviours in tobacco-only outlets, as well as the intention of maximising tobacco profits from tobacco-only outlets by attracting more affluent consumers (see details in section 4.5.2).

8.2.2 Neighbourhood effects on smoking

The majority of findings addressing how neighbourhood environments affect smoking behaviours were based on evidence from HICs and largely relied on a cross-sectional approach, indicating individuals living in more disadvantaged neighbourhoods were more likely to be current smokers,²³⁻³⁵ heavy smokers,^{5,23,35} and less likely to quit.^{24,28,31,36} Although sometimes mixed results were found within the same geographical context, broadly, individuals living in neighbourhoods with better availability of tobacco retailers were more likely to smoke^{7,35,37-41} and less likely to quit.^{41,42} However, findings on the impacts of neighbourhood disadvantage on smoking in LMICs differed from those in HICs, and evidence on the association between tobacco retail availability and smoking in LMICs is lacking. Prior Chinese studies have suggested a positive association between neighbourhood disadvantage and smoking frequency, whereas the impact on current smoking and smoking cessation has not been determined. By providing important local-level evidence in the setting of Shanghai, China, the current thesis enhances the understanding on how local socio-commercial environments affect smoking behaviours by providing robust local-level evidence in Shanghai. Study 3 (Chapter 6) is the first Chinese study that determined the cross-sectional and longitudinal impacts of neighbourhood-level tobacco retail availability on smoking behaviours by indicating the positive impact of tobacco retail availability and neighbourhood deprivation on smoking and the negative impact on smoking cessation.

Findings from Study 3 were somewhat consistent with what had previously been observed in western HICs that greater tobacco retail availability was associated with higher likelihoods of current smoking.^{20,35,41,43} However, this significance was only retained cross-sectionally, not longitudinally. On the contrary, tobacco retail

availability was found to be associated with smoking cessation longitudinally, not cross-sectionally. In terms of the association between neighbourhood deprivation and smoking behaviours, findings from Study 3 are in line with previous findings from HICs^{24,28,31,36} but disagree with findings from other LMICs (e.g. Mexico and South Africa), where a non-linear association was found for the association between neighbourhood deprivation and the likelihood of current smoking.^{44,45} In Shanghai, higher neighbourhood deprivation was associated with increased odds of current smoking and reduced odds of smoking cessation, cross-sectionally, whereas neighbourhood deprivation was only found to be associated with current smoking over time. Findings from Study 3 extend previous evidence on how neighbourhood deprivation affects smoking behaviours in the context of LMICs.

8.2.3 Place-based policies and local tobacco retail market

This thesis further contributes to the knowledge regarding how place-based policies reshape the local tobacco retail market. Evidence regarding the effectiveness of spatial restrictions in reducing tobacco retail availability, inequality, and smoking prevalence is still limited, especially in LMICs such as China, which is also the biggest tobacco producer and consumer worldwide with ubiquitous tobacco retail.⁴⁶ Established studies from HICs suggest the effectiveness of spatial restrictions is context-dependent that the effectiveness of different place-based policies aimed at reducing tobacco retail availability varies across context.⁴⁷⁻⁵⁰ Findings from Study 4 somewhat confirmed prior findings from HICs. Using the case study of Shanghai as its basis, this simulation study reveals the great potential of spatial restrictions in reducing tobacco retail availability and social inequality in tobacco retail availability, as well as the differential impacts of spatial restrictions by levels of urbanity. Study 4 also addressed the possibility that the most effective spatial restriction may increase the social inequality in tobacco retail availability greatly, which agrees with the findings from Scotland.⁵⁰ In contrast to findings from the US,⁴⁹ where higher thresholds had a better equity impact, there is no such relationship in the case of Shanghai. Study 4 (Chapter 7) is the first study that examined the potential impacts of place-based spatial restrictions on shaping tobacco retail availability in the Chinese context using real retail data regarding tobacco.

8.3 Strengths, Limitations, and Future Perspectives

8.3.1 Strengths

8.3.1.1 Strengths in datasets

This thesis has major advantages in the completeness of tobacco retail data. Although the tobacco retail licensing system in China is supposed to track all legitimate tobacco retailers, the registered data is not available for academic purposes. Therefore, previous research investigating tobacco retail in China heavily relied on audit sampling data. However, the random sampling approach may result in incomplete and biased samples of tobacco retailers, such as overlooking the retail distribution in less urbanised areas of the city, especially in the context of Chinese megacities where the administrative area is vast with significant socio-spatial disparities due to rapid urbanisation. For example, Gong et al. (2011) used a random sampling approach to audit 1639 tobacco retailers in 3 more urbanised districts out of 6 districts in Hangzhou.²² Similarly, a more recent study using a random sampling approach investigated 141 tobacco retailers around 128 schools in Shanghai, suggesting 57% of urban schools had a tobacco retailer within a 100 m radius.⁵¹ However, Study 2 examined the patterning of tobacco retailers ($n = 19,413$) around public schools using a sample of public schools that covered the metropolitan area of Shanghai ($n = 1,483$), suggesting 17.8% of public schools across the city of Shanghai had at least one tobacco retailer within 100 m-radius, and this proportion increased to 29.4% within 400 m-radius and to 60.1% within 800 m-radius. Even within the urban centre of Shanghai, where the availability of tobacco retailers was greatest, the proportion of public schools ($n = 273$) in the vicinity of a tobacco retailer within 100 m-radius was 30.4%. This thesis used a more complete sample that included all public schools that intended to enrol new students (including different campuses of the same public school) in Shanghai (2019) and a full coverage of data on tobacco retailers across the metropolitan areas of Shanghai using web-based Points of Interest (POIs). In the context of megacities with significant and more complex socio-spatial disparities, such as Shanghai, a more comprehensive dataset may capture the tobacco retail

environment more precisely, which further indicates web-based POIs as a valid open-source alternative for investigating tobacco retail.

It has been suggested that longitudinal analysis can better reflect the causality as compared to cross-sectional analysis.^{52,53} Although certain Chinese cohorts (such as the China Family Panel Studies and the China Health and Retirement Longitudinal Study) contain neighbourhood-level variables, the majority of them are not able to be linked with tobacco retail availability data, which was produced using other datasets. The International Tobacco Control China Survey (ITC China) enables data linkage at the residential community level with a cohort across 5 waves, offering a perfect opportunity to study the impacts of neighbourhood socio-commercial characteristics in relation to individual-level smoking behaviours in Shanghai over time, which reveals the significant negative association between tobacco retail availability and smoking cessation and the significant association between neighbourhood deprivation and current smoking over time. This is the first time that local-level evidence regarding the longitudinal impact of tobacco retail availability on smoking behaviours has been determined in the Chinese context.

8.3.1.2 Strengths in analyses

Study 1, Study 2, and Study 4 used different types of spatial analysis, including population-weighted KDE, network-based service area analysis, and spatial cluster analysis, to analyse the point pattern of tobacco retailers, which enables a more accurate estimation of tobacco retail availability under different environmental settings. Conventionally, due to its characteristic of easily being operationalised, the count of tobacco retailers or the count of tobacco retailers per capita has been widely applied to estimate tobacco retail availability, while KDE has been suggested to have better performance in estimating tobacco retail availability.⁵⁴ Findings from Study 1 verified this viewpoint, showing neighbourhood tobacco retail availability estimated by population-weighted KDE statistically differed by levels of neighbourhood deprivation, while significance was not found in previous studies in Changsha, China, which used the count of tobacco retailers per neighbourhood to assess tobacco retail availability.¹³

Study 2 provides more robust evidence on the characteristics of the local tobacco retail environment around public schools in Shanghai. Firstly, a network-based service area analysis was performed to estimate the availability of tobacco retailers around schools. Compared with conventional buffer analysis using Euclidean distance, a network-based analysis could estimate tobacco retail exposure more precisely by capturing the exposure along the roads through simulating the walking environments. Furthermore, although previous studies in China also suggested the high availability of tobacco retailers around schools,^{51,55,56} none of them determined whether tobacco retailers were more clustered around public schools. Study 2 used spatial cluster analysis at multiple distances, suggesting there was a significant clustering pattern of tobacco retailers towards public schools in Shanghai, which further varied by levels of urbanity, types of schools, and types of tobacco retailers. This thesis validates the great potential of spatial analysis in analysing environmental exposure, such as tobacco retail exposure, for public health intervention.

Furthermore, Study 4 suggested the great potential of using a spatial thinning approach in simulating the plausible impacts of spatial restrictions aimed at reducing tobacco retail availability. The spatial thinning approach has been previously used in ecological niche modelling.⁵⁷ Previous studies simulating the impacts of spatial restrictions on the tobacco retail market normally used more complex methods, such as agent-based models (ABM),^{47,48} to model the stochasticity. Caryl et al. (2020) first used the spatial thinning approach to simulate the tobacco retail environment under a variety of spatial restrictions.⁵⁰ Compared with complex simulation models^{47,48} and conventional geographical approaches,⁵⁸ spatial thinning is easier to operationalise and enables the creation of policy scenarios with stochasticity. In the context of China, local TMBs are obliged to regulate and oversee the local tobacco retail market, enact regulations (such as spatial restrictions), and develop tobacco control initiatives. The convenience of spatial thinning in operationalisation may better serve research on local-level tobacco retail markets as well as local-level administration and policymaking in practice.

8.3.2 Limitations

This current thesis has some limitations.

Data on the neighbourhood socio-commercial environment, including tobacco retail availability and neighbourhood deprivation, were compiled separately at different time points. Namely, tobacco retail availability was estimated using the web-based POIs in 2019, while the neighbourhood deprivation index was calculated using the 2010 Chinese census data. In examining the tobacco retail patterning across the metropolitan area of Shanghai, the land in some urban periphery areas of Shanghai has been turned from cultivated purposes to residential or commercial purposes, so the experienced neighbourhood-level social transition during 2010-2019 might be neglected.

Furthermore, while this thesis investigates the relationship between neighbourhood socio-commercial environments and smoking behaviours over time, the neighbourhood-level social commercial variables, such as tobacco retail availability and neighbourhood deprivation, were both collected at a single time point, whereas individual-level data were collected over time. However, the POI data on tobacco retailers and the census data were the latest data at the time, with no available open-sourced archived POIs that could be used.

Additionally, the examination of the cross-sectional and longitudinal impacts of tobacco retail availability and neighbourhood deprivation on smoking behaviours failed to use the same approach due to the sample size of clusters of individual data is not sufficient enough for 3-level logistic regression. Instead, a Generalised Estimating Equation (GEE) approach was applied to examine the impact of neighbourhood socio-commercial environment on smoking behaviours over time.

8.3.3 Future perspectives

This research could be taken forward in several ways.

In terms of future perspectives to theories, firstly, future studies may specifically address smoking relapse, particularly in the Chinese context, where there is a lack of evidence on the subject. This thesis explains the relationship between neighbourhood socio-commercial environment and smoking behaviours cross-sectionally and longitudinally, suggesting the positive impacts of tobacco retail availability and neighbourhood deprivation on smoking and the negative impacts of both on smoking

cessation among male adults in Shanghai, China. However, due to the limited sample size of the cohorts regarding smoking cessation in Shanghai, this thesis is not able to examine the impact of socio-commercial environments on smoking relapse. More robust evidence regarding the neighbourhood effects on smoking relapse is urgently needed, not just in the Chinese context.

Secondly, in addition to determining the impact of tobacco retail availability and neighbourhood deprivation on smoking, more exploration of place-based pathways of smoking needs to be conducted in the Chinese context. There is a culture of smoking in China.⁵⁹ Even though female smoking has been strongly disapproved in the past, smoking is less stigmatised in the Chinese context than it is in Western HICs.⁵⁹ Served for social functions,⁶⁰ cigarette gifting has been considered a kind of social currency,⁶¹ while cigarette sharing forms part of community identification and social currency.^{62,63} Future studies may further examine how places could be linked to smoking through multiple socio-cultural pathways (e.g. social norms, social contagion, social cohesion, and social participation) using quantitative and qualitative methods.

Thirdly, robust evidence on the tobacco retail environment around "child space" is anticipated. As a predictor of smoking/smoking initiation and smoking cessation,⁶⁴ the availability of tobacco retailers is disproportionately distributed in more vulnerable neighbourhoods.^{1,3-11} The existing evidence has a shortcoming in that the investigation into the environment for the underage is either residential or school.^{42,65} This thesis examined the retail availability of tobacco within residential neighbourhoods and around public schools in Shanghai, China, as well as the impact of the neighbourhood availability of tobacco retailers on smoking behaviours among male adults. The retail exposure to adolescents in a variety of "child spaces" (e.g. playgrounds, greenspaces) and its impact on smoking behaviours have not been investigated in the Chinese context, which calls for a particular focus on that in the future.

Additionally, it is crucial to explore further the relationship between tobacco retail availability, neighbourhood deprivation and smoking, as well as the local-level policy impacts on that in other Chinese cities. The impacts of the socio-commercial environment may vary greatly across geographical areas, especially in a country like China where urban development is uneven across regions, the administrative area is

vast and the geographical disparities in smoking prevalence are significant. More robust local-level evidence is critical for the development of effective tobacco control initiatives.

In terms of future perspectives in methodologies, in addition to requiring high-quality and quantity data on the neighbourhood environment and individual smoking over time, it is worthwhile to explore the impacts of changes in local environments on transitions in tobacco retail patterning and smoking behaviours over time in the Chinese context using appropriate longitudinal data in the future.

Because of the different approaches that have been adopted to measure tobacco retail availability, there may be inconsistency in findings regarding the association between tobacco retail availability and smoking, which also impedes interpretation of this relationship.^{54,66} On the other hand, as suggested by Lee (2021), the place-based initiatives for tobacco retail availability reduction were mostly constrained and implemented by administrative boundaries.⁶⁶ More advanced technologies or measurements, such as the Global Positioning System (GPS), could be considered. The use of GPS enabled tracking down the tobacco retail exposure of individuals, children in particular,⁶⁷ which provides a more precise estimate of the real exposure to tobacco retail. Furthermore, rather than capturing the retail exposure within static residential areas, GPS offers the possibility of capturing dynamic exposure in activity space, which may better facilitate future place-based policymaking.

This thesis used a simulation method to evaluate the effectiveness of spatial restrictions in reducing tobacco retail availability and social inequality in tobacco retail availability, but their impacts on smoking behaviours as well as the thresholds of spatial restrictions in reducing smoking prevalence have not been tested. Along with the more comprehensive dataset regarding neighbourhood and individual-level characteristics, more complex models, such as agent-based models (ABMs), could be utilised to further study the impacts of local-level spatial restrictions on actual smoking behaviour by simulating the dynamics of the retail market and the stochasticity of individual-level smoking and purchase behaviour.

8.4 Policy Implications

Findings from all four studies in this thesis have important policy implications through local-level insights for tobacco control policymaking in the Chinese context, particularly for the megacities of China. Truly, progress in tobacco control has been made in China in recent years, particularly in smoke-free policies, health warnings and education campaigns, and youth access laws.⁶⁸ However, a gap remained in impeding the interference from the tobacco industry, regulating the content of tobacco products, promoting alternative livelihoods, and protecting a healthy environment.⁶⁸ Goals including reducing smoking prevalence to 20% and reducing health inequalities, have been proposed in *Healthy China 2030*.^{69,70} Given the remaining gap, more efforts need to be made to achieve the goals proposed in *Healthy China 2030*.⁷⁰ The policy implications of this current thesis will be discussed in several aspects.

Overall, this thesis indicated that there is an impact of tobacco retail availability on current smoking and smoking cessation, suggesting that regulating tobacco retail availability as part of comprehensive tobacco control strategies may remain the potential to reduce smoking prevalence in China, particularly in megacities. Along with the finding regarding the positive association between neighbourhood deprivation and current smoking, restricting tobacco retail in the most deprived neighbourhoods may both encourage current smokers to quit as well as reduce the odds of smoking initiation. Other tobacco control initiatives, such as smoking cessation programmes, may also consider a focus on residents from more deprived backgrounds.

Previous studies suggest that tobacco retail licensing can prevent smoking initiation and support smoking cessation⁷¹ by discouraging tobacco sales,⁷² improving compliance with retail regulations,^{73,74} and denormalizing tobacco use.⁷¹ Tobacco retail licensing has a long history in China. However, except for tracking tobacco retailers, the licensing system has not fulfilled its potential in public health, such as regulating tobacco retail availability at the local level. This thesis uncovers the significant disparities in tobacco retail patterning by levels of deprivation and urbanity, calling for policymakers to be aware of the current socio-spatial disparities in tobacco retail availability during the process of local-level tobacco retail licensing. In addition

to reducing the overall availability of tobacco retailers, considering the significant disparities in tobacco retail availability by different types of tobacco retailers, this thesis further calls for regulating retailer types in the process of licensing. Regulating retailer types may further strengthen tobacco control by restricting the differential advertising and promoting activities in certain types of tobacco retailers,⁷⁵ which have been proved to have a negative impact on smoking initiation and smoking cessation among customers through normalising tobacco use, imposing impulse tobacco purchases, and triggering environmental cues.^{16,17,37,76,77}

This thesis suggests that the thresholds of spatial restrictions on prohibiting tobacco sales around schools should be increased. This policy has been legislated nationally in China in 2021,⁷⁸ which is a spatial restriction that has not been widely adopted in western HICs. However, this policy was enacted by the local TMB, which resulted in the various thresholds across Chinese cities. In Shanghai, the current threshold is 50 m from the main entrance of a school. Examining the compliance of tobacco retailers, Study 2 showed that about 17.8% of tobacco retailers might fall within the 100 m-radius buffer, while 60.1% of tobacco retailers were allocated within 800 m-radius (a plausible 10-min walking distance). Even though tobacco retailers were not permitted to sell tobacco products within a 50 m-radius buffer around schools, students could be exposed to tobacco retail along with the advertising and promotion activities at the point of sale on their daily routes to schools or during lunch time. In order to prevent earlier smoking initiation among the students, it is critical to increase the thresholds for prohibiting tobacco sales around schools. Although most tobacco retailers in Shanghai complied with spatial restrictions, there were still about 5.9% of public schools that might be exposed to illicit tobacco retail. Considering the 50 m prohibiting distance is such a sensitive distance, in addition to increasing the thresholds of spatial restrictions, this finding further requires a more clear statement in describing the details of the spatial restrictions for better compliance.

The current thesis further examines the effectiveness of spatial restrictions in reducing tobacco retail availability and the social inequality in tobacco retail availability in Study 4. All types of spatial restrictions enable reducing tobacco retail availability, albeit varied by levels of urbanity. In conjunction with findings from Study 3, spatial

restrictions aimed at reducing tobacco retail availability may be capable of reducing smoking prevalence as well. However, as the most effective spatial restriction, requiring a minimum distance between two neighbouring tobacco retailers increased the social inequality in tobacco retail availability the most. While prohibiting tobacco sales around schools had the second highest effectiveness in reducing tobacco retail availability, it enabled a considerable reduction in social inequality. Addressing the underlying social inequalities in the effectiveness of spatial restrictions, this thesis suggests policymakers be cognisant of socio-spatial disparities in the effectiveness of spatial restrictions and the possibility that spatial restrictions may also increase social inequality. To effectively reduce tobacco retail availability and the corresponding social inequality, policymakers may first consider the neighbourhood-level socio-spatial characteristics during the process of enforcing spatial restrictions regarding tobacco retail.

8.5 Conclusions

To conclude, this thesis contributes to the literature by enhancing understanding of whether and to what extent tobacco retail patterning differs by neighbourhood social environments; how neighbourhood socio-commercial environments affect individual-level smoking behaviours; and how place-based tobacco retail policies could help to reshape the local tobacco retail market, with a particular focus on Shanghai, China's largest and most developed megacity.

This thesis also underlines the potential of regulating tobacco retail availability for effective tobacco control in China. Considered as a “new frontier” of tobacco control,⁷⁹ greater potential exists for more systematic and stricter spatial restrictions aimed at reducing the availability of tobacco retail to prevent smoking initiation, discourage tobacco use, and promote smoking cessation. These place-based restrictions could be applied in conjunction with China's well-established tobacco retail licensing system.

Finally, this thesis indicates that the dual roles of local TMB in promoting tobacco sales and regulating tobacco retail have posed barriers to effective tobacco control. In the case of Shanghai, the lack of separation between the tobacco administration and the tobacco industry may contribute to intensifying the socio-spatial differences in tobacco retail availability and result in the widespread availability of convenience stores across the metropolitan area, which may further increase the socio-spatial inequalities in smoking. In spite of the progress in tobacco control in recent years, to achieve the ambitious goals that were detailed in *Healthy China 2030* and to reduce the enormous health and economic burden resulting from tobacco use,⁷⁰ a further separation between the tobacco administration and the tobacco industry should be anticipated in China.

8.6 References

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