**WeProtocol for A Natural Experiment Design to Evaluate the Impact of a Smoke-Free Housing Policy on Secondhand Smoke-Related Health Outcomes Using Propensity Score Matched Samples**

Byoungjun Kim1,2

Katarzyna Wyka3

Brian Elbel1

Alexis Feinberg3

Donna Shelley~~4~~

Lorna Thorpe1

1. Department of Population Health, School of Medicine, New York University, New York, New York, USA

2. Department of Epidemiology, Mailman School of Public Health, Columbia University, New York, USA

3.. Graduate School of Public Health and Health Policy, City University of New York, New York, NY, USA

4. New York University College of Global Public Health, New York, New York USA

**Address Correspondence to:** Lorna Thorpe, PhD

NYU School of Medicine, Department of Population Health, 180 Madison Ave, 5th Floor, New York, New York 10016 E-mail: Lorna.Thorpe@nyulangone.org

**Abstract**

**Background:** Approximately 41,000 deaths are due to secondhand smoke (SHS) in the United States annually, and 58 million non-smokers remain exposed to SHS, primarily in the home. Risk is particularly high among multi-unit housing residents.This paper describes the design and protocol of a natural experiment study to assess health impacts of a federal smoke-free housing (SFH) policy that bans smoking in public housing buildings beginning July 2018.

**Methods:**  The study uses large administrative datasets to contrast pre- and post-policy health trajectories in SHS-related health conditions between New York City Housing Authority (NYCHA) residents and a matched comparison among New York City (NYC) population. We performed a propensity score match to pair residents living in NYCHA housing with a sample of NYC residents living in census block groups (CBGs) without public housing, matched on aggregated sociodemographic and environmental characteristics. We used emergency department (ED) visit and hospitalization data from the New York State Statewide Planning and Research Cooperative System (SPARCS) combined with population data from the American Community Survey and NYCHA Tenant Data System to monitor rates in asthma ED visits among children ages 0-18, and myocardial infarction (MI) and stroke hospitalizations among adults ages 50 and older. We analyzed 2016 SPARCS data in preparation for a difference-in-difference analysis of full pre- (August 2016 – July 2018) and post-policy periods (August 2018 – July 2020).

**Results:** A total of 619,092 NYC residents lived in CBGs that were matched in a balanced design (standardized mean difference < 0.1) to 390,978 residents officially residing in NYCHA housing. In 2016 the asthma ED visit rate among children in NYCHA housing was consistently higher than among children living in comparison CBGs (annual average of 70 vs 39 cases/1,000 population). Among elderly adults, MI and stroke hospitalization rates were consistently higher in the NYCHA intervention group (MI: annual average of 6.5 vs. 4.6 cases/1,000; stroke: 7.1 vs. 6.1 cases/1,000).

**Conclusion:** This study design offers an opportunity to rigorously investigate the impact of SFH policy on SHS-related health outcomes by employing a community-level matching process using multiple secondary datasets.

**Keywords:** Public Housing, Smoke Free Housing, Policy Evaluation, Propensity Score Matching, Protocol

**Background**

Secondhand smoke (SHS) contains more than 4,000 toxic chemicals. Approximately 41,000 deaths are attributed to SHS in the United States (U.S.) each year.1 SHS causes cancers, coronary artery disease, stroke and respiratory problems among non-smoking adults and elevates risks of congenital defects and sudden infant death syndrome among children.1,2 It also increases risks for lower respiratory tract infections, otitis media, and the number and severity of asthma attacks in children with asthma.1 Although comprehensive smoke-free laws in workplaces and public spaces have reduced SHS exposure in the U.S.,3-6 58 million non-smokers remain exposed to SHS, and the risk is particularly high among residents living in multi-unit housing.3

More than 2 million individuals live in public housing in the U.S.7 Risk for SHS exposure is generally higher among public housing residents than general population for two reasons. First, despite overall declines in smoking over time in the U.S., reductions in smoking have been slower among lower-income populations.8 Studies have confirmed that residents living in public housing, who are predominantly lower income and racial/ethnic minorities, have higher smoking rates than the general population.9-12 Second, most public housing is multiunit in structure with higher population density, which elevates the risk of SHS exposure by accumulating smoke compared to detached housing environments.13 Several studies have confirmed that residents in multi-unit housing are at elevated risk for SHS.14-17 For example, one study conducted using a national representative sample in the U.S. found that children of non-smoking families living in multi-unit housing had 45% higher serum cotinine levels than children who lived in non-smoking single-family housing.15

Responding to this evidence, on November 30, 2016, the U.S. Department of Housing and Urban Development (HUD) passed a rule that required all public housing agencies to implement smoke-free housing (SFH) policies by July 30, 2018.18 The regulation mandated any housing authority administrating low-income conventional public housing prohibit the use of all tobacco products including cigarettes, cigars, pipes, and hookah in residential units, indoor common areas, and within 25 feet of buildings. To the best of our knowledge, there are no empirical studies that have evaluated the impact of SFH policies on SHS-related health outcomes. Protective impact of smoke-free laws in workplaces on SHS-related diseases has been thoroughly examined,19-23 yet that of SFH policies are still remained to be investigated. To date, only one study has assessed health outcomes associated with smoking bans by examining self-reported changes in health outcomes among 115 Colorado Public Housing Authority (PHA) residents in three buildings, pre- and one year post-policy implementation; the authors found a significant decrease in self-reported breathing problems.24

This paper describes a protocol to assess the impact of SFH policy on SHS-related health outcomes by comparing New York City Housing Authority (NYCHA) residents to a matched comparison population in New York City (NYC) without the policy through a natural experiment study design. NYCHA is the largest housing authority in the U.S. with approximately 400,000 official residents which comprise about 15% of all public housing residents in the U.S.25 The approach uses geo-coding and data linkage techniques to measure health outcomes for NYCHA housing residents and residents in selected comparison neighborhoods from a fully comprehensive citywide hospitalization and ED data source over time. This study design reduces selection bias by exposing whole target populations to an intervention in a quasi-experimental fashion. We designed the study to investigate SHS-related health outcomes for two years pre- (August 2016 – July 2018) and post-policy (August 2018 – July 2020) to achieve robust sample sizes and statistical power. However, causal inference from this design is still susceptible to potential biases due to selective exposure to intervention and selection of unexposed group.26 As such, we implemented analytic techniques and additional study design features to further reduce bias.

This paper describes the study design and analytic protocol to examine the impact of the policy on health outcomes in detail. The larger study, funded by the National Cancer Institute (NCI), also evaluated whether the federal policy was associated with reductions in air nicotine and PM2.5 levels one year after the policy went into effect using extensive monitoring in a sample of 10 NYC public housing and 11 Section 8 high-rise buildings. Published elsewhere, we found no differential change in air nicotine levels in NYCHA apartments or stairwells compared to Section 8 buildings one year after the policy went into effect.27,28 Prior qualitative analyses have identified a range of barriers to implementing SFH policies,29,30 but continued evaluation of the implementation process and assessment of impact on health outcomes is critical to guide both future policy pertaining to smoking in housing settings and inform public support.

**Methods**

**Study Design**

We employed a natural experiment study design with a matched comparison population to monitor SHS-related health outcomes during a period of 2-year pre- and post-policy. To further reduce potential biases of a natural experimental study design, we first employed propensity score matching, a matching procedure that reduces treatment-selection bias.31 Propensity scores measure the probability of receiving a specific treatment conditional on the observed covariates;32 conditioning on the propensity score thus eliminates a great proportion of baseline differences between treatment and comparison groups in an attempt to replicate characteristics of a randomized controlled trial.33 Second, we selected a difference-in-difference (DID) analytic approach to allow assess pre- and post-policy differences between the intervention and selected comparison groups. Lastly, we proposed using negative control outcomes, which can support causal inference by assessing outcomes not expected to change due to the intervention but potentially vary with respect to anticipated potential confounders.34 Outcomes of interest will be calculated among the NYCHA public housing resident population and compared to trajectories in the same periods among a matched sample of NYC residents living in census block groups (CBGs) containing no public housing units. Because the 2017 SPARCS dataset was not available for public access, we only analyzed 2016 SPARCS data and present results here.

**Study Outcomes**

Primary health outcomes of interest include: (1) pediatric asthma emergency department (ED) visits among children under age 18, (2) hospitalizations for stroke and (3) myocardial infarction (MI) among adults age 50 and older, each chosen for their potential sensitivity to SHS exposure.1,2,35-42 Health outcome data are collected as part of Statewide Planning and Research Cooperative System (SPARCS), a comprehensive all hospitalization data reporting system for New York State. Outcomes are defined using SPARCS principal diagnosis code (ICD-10-CM: asthma-J45, myocardial infarctions-I21, stroke-I61, I62, I63) as well as an emergency department indicator for pediatric asthma cases. Previous studies have demonstrated that utilization of ED visits has strengths in tracking acute illnesses as well as in determining chronic disease prevalence, including asthma, at a local level.43,44 Incident ED visits or hospitalizations are calculated per 1,000 population.

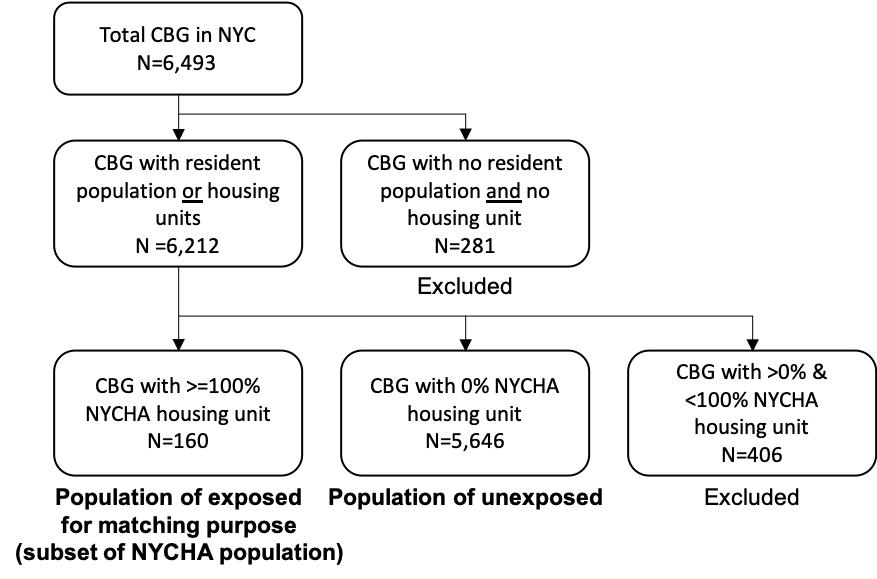
**Study Population**

All official NYCHA residents were selected into the intervention group based on the Tenant Database maintained by NYCHA. ED visits or hospitalizations of NYCHA residents were ascertained through linkage of geocoded residential addresses of patients in the SPARCS data to a list of all NYCHA properties as of July 2018. As address information in SPARCS data has variations, i.e., different abbreviations and unit numbers, the use of geocoded addresses yielded more accurate and higher matching rate than scanning addresses. Specifically, residential addresses of patients in SPARCS were geocoded to identify the Borough-Block-Lot (BBL), a geographic identifier of tax lots, using a geocoding package (New York City Geosupport version 19.A) provided by NYC Department of City Planning, with match rates averaging 95%. The listed NYCHA building addresses were geocoded with the same method. A total of 880 BBLs were identified as NYCHA intervention group tax lots, and SHS-related health outcomes from SPARCS data joined to the 880 NYCHA BBL were identified as visits or hospitalization events occurring to NYCHA residents.

**Propensity Score Matched Comparison Group**

To select a comparison group matched on relevant socio-economic status and reduce residual confounding, we employed propensity score matching methods using multiple datasets to include a range of relevant baseline variables.45 Although the actual NYCHA intervention group was constructed using NYCHA tenant data and shapefiles (described above), a census-based proxy intervention group was also required in order to generate the comparison group based on neighborhood-level socio-demographics.

For this, we used the 2016 American Community Survey (ACS) 5-year estimate data. As CBG is the smallest geographical level with detailed socio-economic status information, it served as the unit of analysis for the matching. We first assigned all CBGs comprised solely of NYCHA tax lots for the purpose of conducting the propensity score match to generate the comparison population group. Specifically, the aggregated number of NYCHA housing units within CBGs was divided by the total number of housing units. When the 90% interval contained 1.00 (100%), the CBG was categorized as “100% NYCHA”. A total of 160 CBGs were selected as a census-based proxy intervention group for the matching purpose (Figure 1). These 160 CBGs were used only for generating the comparison group. CBGs without any NYCHA housing units were selected as the pool from which the comparison group would be selected. To prevent crossover, CBGs with more than one NYCHA housing units but less than 100% (n=406) were excluded from the analysis. Of note, housing units were selected as the unit of analysis instead of population due to uncertainty regarding the comparability of population estimation accuracy between CBGs of NYCHA and non-NYCHA residents.



*Matching variables*

A set of variables characterizing the socio-economic status of CBG residents was included in the matching process. Using the 2016 ACS 5-year estimates, we constructed proportions of populations across three age groups (0-17, 18-50, 50 over), two racial/ethnic groups (Black and Hispanic), and two mutually exclusive poverty status (below 100% and between 100%-125% federal poverty levels).

In order to address potential confounding due to building structures and physical characteristics of neighborhood, one built environment variable, residential density of CBG, was also included in the matching process. The residential density was constructed by dividing total residential floor areas in CBGs by the total lot areas in the CBG, based on NYC PLUTO 17v1.1 dataset. This variable served as a proxy measure of multi-unit housing and population density in CBG.

*Propensity Score Matching Results*

Propensity score matching analysis was performed using MatchIt packages on R software. All 8 covariates mentioned above were included, and the “nearest neighbor matching” method was applied with a ratio of 4 and a caliper width equal to 0.2 times the standard deviation of the logit of the propensity score.46 Finally, the matching balance of each covariate was evaluated with a criterion of standardized mean difference less than 0.1.47

A total of 156 NYCHA CBGs (90% of the census-based proxy intervention group) were matched to 484 non-NYCHA CBGs. The population in the non-NYCHA CBGs will be compared to official NYCHA population based on abovementioned BBL identifier. Matching results (Table 1) indicate a balanced match (standardized differences < 0.1) for all neighborhood-level covariates used in the matching process.

Table 1. Propensity Score Matching Results

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Unmatched**  **(160 vs. 5646 CBGs)** | | |  | **Matched**  **(154 vs. 484 CBGs)** | | | |
|  | NYCHA | Comparison Pool | Std. Diff. |  | NYCHA | Matched Comparison | Std. Diff. | |
| **Poverty (%)** | | | | | | | |
| 100% FPL | 44.7 | 18.0 | 2.07 |  | 44.2 | 43.8 | 0.03\* | |
| 125% FPL | 9.7 | 4.9 | 0.74 |  | 9.7 | 9.5 | 0.03\* | |
| **Age group (%)** | | | | | | | |
| 0 to 17 | 26.2 | 20.1 | 0.65 |  | 26.3 | 26.5 | 0.02\* | |
| 18 to 49 | 41.9 | 47.7 | 0.69 |  | 42.1 | 42.8 | 0.08\* | |
| 50 over | 31.9 | 32.2 | 0.02 |  | 31.6 | 30.7 | 0.08\* | |
| **Race/Ethnicity (%)** | | | | | | | |
| Hispanic | 50.3 | 26.4 | 1.32 |  | 49.9 | 51.6 | 0.10\* | |
| Non-Hispanic Black | 39.5 | 19.9 | 1.06 |  | 39.7 | 38.3 | 0.08\* | |
| **Built Environments** | | | | | | | |
| Residential FAR | 1.6 | 1.9 | 0.33 |  | 1.627 | 1.6 | 0.06\* | |

\* Standardized differences < 0.1

To confirm the validity of the neighborhood-level propensity matching process and to maximize the comparability, we evaluated all-casue hospitalization patterns and socio-economic status of inpatient data between the intervention and comparison groups using SPARCS data (Table 2). Despite the balanced neighborhood-level matching results, demographic characteristics of individual inpatient showed differences. This indicated that further adjustment for additional variables in the analysis stage.

Table 2. All-cause Hospitalization Pattern between NYCHA population and comparison group, SPARCS 2015-2017 Datasets

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2015** | | | | **2016** | | | | **2017** | | | |
|  | **NYCHA** | | **Matched\*** | | **NYCHA** | | **Matched\*** | | **NYCHA** | | **Matched\*** | |
| **SEX** | | | | | | | | | | | | |
| Female | 49,794 | 62% | 52,972 | 56% | 48,957 | 61% | 52,729 | 56% | 36,516 | 61% | 39,990 | 55% |
| Male | 31,082 | 38% | 41,884 | 44% | 30,711 | 39% | 41,654 | 44% | 23,085 | 39% | 32,817 | 45% |
| **RACE** | | | | | | | | | | | | |
| Asian | 1,267 | 2% | 1,683 | 2% | 1,481 | 2% | 1,768 | 2% | 1,246 | 2% | 1,489 | 2% |
| Black | 40,816 | 50% | 38,539 | 41% | 39,556 | 50% | 38,175 | 40% | 27,950 | 47% | 29,266 | 40% |
| White | 7,645 | 9% | 13,484 | 14% | 7,466 | 9% | 13,645 | 14% | 5,477 | 9% | 9,921 | 14% |
| Other | 31,148 | 39% | 41,150 | 43% | 31,165 | 39% | 40,795 | 43% | 24,928 | 42% | 32,131 | 44% |
| **ETHNICITY** | | | | | | | | | | | | |
| Non-His | 52,476 | 65% | 58,672 | 62% | 52,707 | 66% | 60,176 | 64% | 37,265 | 63% | 42,486 | 58% |
| His | 22,933 | 28% | 25,913 | 27% | 22,352 | 28% | 26,542 | 28% | 16,084 | 27% | 21,222 | 29% |
| Other | 5,467 | 7% | 10,271 | 11% | 4,609 | 6% | 7,665 | 8% | 6,252 | 10% | 9,099 | 12% |

\* Defined as inpatients who lived in propensity-score-matched census block groups. His: Hispanic

**Statistical Analysis Plan**

Residents living in the intervention and selected comparison settings will be followed for 2 years after the SFH policy, and monthly and semi-annually incidence rates of the three outcomes will be compared using a difference-in-difference (DID) approach for repeated measures via Poisson models. We conducted a preliminary assessment of the parallel-trend assumption of DID using rates of SHS-related conditions in intervention and comparison settings during 2-year pre-policy period.48 The final DID model will include fixed-effect for: (1) intervention vs. comparison sites, (2) post-implementation time-periods, and (3) intervention and time interaction, adjusting for within-building, within development, and seasonality.49-51 Finally, additional covariates, such as sex and race, will be further adjusted in the models based on the review of hospitalization pattern abovementioned (Table 2).

In order to test the robustness of study findings from the propensity score matching, we will also compare health outcomes in the census-based proxy intervention group (160 CBGs) to official NYCHA residents from NYCHA Tenant Database.

**Results**

Descriptive statistics by treatment assignment are provided in table 3. Compared to the matched control group, NYCHA residents had a greater share of non-Hispanic black (45% vs. 38%), less Hispanic (45% vs. 52%), and higher poverty rates (100% federal poverty level: 49% vs. 44%; 150% federal poverty level: 12% vs. 10%).

Table 3. Descriptive statistics of NYCHA population and comparison groups, NYCHA Tenant Database and 2016 5-year estimate American Community Survey

|  |  |  |
| --- | --- | --- |
|  | **NYCHA** | **Matched** |
| **Total Population** | 390,978 | 619,092 |
| **Age Distribution** |  |  |
| 0-17 | 26.9% | 26.5% |
| 18-49 | 39.2% | 42.8% |
| 50+ | 33.9% | 30.7% |
| **Race/Ethnicity** |  |  |
| Hispanic | 44.8% | 51.6% |
| Non-Hispanic Black | 45.1% | 38.3% |
| **Poverty** |  |  |
| below 100% FPL | 48.9% | 43.8% |
| 100% - 125% FPL | 11.9% | 9.5% |

Table 4 shows rates of the selected health outcomes during the pre-policy year (2016). Prior to policy implementation, the asthma ED visit rate among children under the age of 18 living in NYCHA communities was higher (annual average of 73.5 vs. 40.0 cases per 1,000 population) in the NYCHA group. MI and stroke ED hospitalizations among people aged over 50 showed also higher rates in intervention group (MI: annual average of 6.7 vs. 4.6 cases/1,000, stroke: 7.2 vs. 5.9 cases/1,000).

Given these pre-policy rates and a sample size of 390,987 residents in the NYCHA group and 619, 092 residents in the non-NYCHA matched comparison group, this study will have sufficient power (80% at alpha level of 0.05) to detect a relatively small risk ratio difference between the intervention and comparison groups. Specifically, we estimated the smallest detectable risk ratio difference is .03 for pediatric asthma ED visits, .004 for stroke and .003 for MI from baseline to 2 years post-policy implementation.

Table 4. Rates of health outcomes in 2016 between NYCHA population and comparison group, SPARCS 2016 Dataset

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **NYCHA** | | | **Matched** | | |
|  | Cases | Population | rate/1,000 | Cases | Population | Rate/1,000 |
| **Asthma ED (under 18)** | 7,723 | 105,131 | 73.46 | 6,691 | 167,106 | 40.04 |
| **MI Hospitalization (50+)** | 891 | 132,462 | 6.73 | 802 | 175,233 | 4.58 |
| **Stroke Hospitalization (50+)** | 953 | 132,462 | 7.19 | 1,028 | 175,233 | 5.87 |

**Discussion**

This paper describes the methodological approach designed to evaluate whether a federal policy to ban smoking in PHAs results in health outcome improvements using a natural experiment design and geocoded hospital encounters obtained from large administrative datasets. This design offers a unique opportunity to investigate the impact of SFH policy on SHS-related health outcomes, which to date has only been assess by self-report in small samples.24 A set of study design features, including propensity score matching, multiple baseline design and DID approach, were selected to address inherent biases in the observational study design. Despite stark differences in population demographics between NYCHA residents and NYC residents living in census block groups containing no public housing units, propensity score matching allowed for selection of an appropriate comparison group, with low standardized differences between comparison groups. While NYCHA residents had higher rates of adverse health outcomes than the comparison group, DID designs require parallel trends rather than comparable outcomes between groups, thus higher outcomes prior to policy enactment can be accommodated. Such study designs can be useful for other policy evaluation studies where information on comparison groups are limited.

**Conclusion**

Findings from this study may inform the design and implementation of future SFH policies in multi-unit housing.

**Abbreviations**

BBL Building Block Lot

CBG Census block group

DID Difference-in-differences analysis

ED Emergency Department

HUD Housing and Urban Development

NCI National Cancer Institute

NYC New York City

NYCHA New York City Housing Authority

PHA Public Housing Authority

SFH Smoke-free housing

SHS Secondhand smoke

SPARCS Statewide Policy Analysis and Research Computing System

U.S. United States

**DECLARATIONS**

**Ethics Approval and Consent to Participate**

The study protocol and procedures were approved by the Institutional Review Board at the New York University School of Medicine on July 20, 2017. IRB number: S17-0968.

**Consent for Publication**

Not applicable

**Availability of Data and Materials**

The datasets used during the current study are available from the corresponding author on reasonable request.

**Competing Interests**

The authors declare that they have no competing interests

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**Authors’ Contributions**

LT, DS and BE conceptualized the approach to assess health impacts of the SFH housing policy. LT, BE and AF prepared the initial propensity scores. BK refined and finalized propensity score approach and led the writing of the manuscript. LT provided ongoing scientific input and multiple rounds of edits on the draft manuscript. KW provided statistical input and edits to the manuscript. DS, BE, TJ and AF provided editorial and scientific comments to the draft manuscript. All authors have read and approved the manuscript.

**Conflicts of Interest**

The authors have no potential conflicts of interest to report.

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**Figure titles**

Figure 1. Group Selection for Propensity Score Matching