Noise and the City: Leveraging crowdsourced 311 data to examine the spatio-temporal relationship between urban development and noise annoyance

Hong, Andy[*†], Kim, Byoungjun, Widener, Michael

Abstract

This study investigates the spatio-temporal relationship between urban development and noise annoyance in Vancouver, Canada. Noise is one of the most frequently complained nuisances and public health hazards in many cities. Chronic exposure to noise is known to increase stress levels and decrease work productivity. While traffic-related noise has been studied extensively, research on other sources of noise has been lacking. Using a historical inventory of major development projects and novel crowdsourced citizen report data from 2011 to 2016, this study finds that neighborhood noise complaints are significantly associated with year (IRR = 1.074, 95% CI = 1.053–1.098) and counts of major construction (IRR = 1.059, 95% CI = 1.026–1.093), while controlling for neighborhood-level confounders. To our knowledge, this is one of the first studies to empirically show adverse effects of urban development on neighborhood wellbeing with respect to noise. Results inform urban planning policies and decisions for determining how and where to target more concerted effort to mitigate chronic noise problems in rapidly growing cities.

Keywords: noise; annoyance; 311; construction; development; crowdsourcing; spatiotemporal; smart cities

Highlights:

- Demonstrated a novel use of crowdsourced data for noise research
- Construction activities were positively associated with noise complaints
- Provided evidence that construction noise can persist during sleeping hours
- Noise bylaws should be amended to restrict after-hours construction

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[*] This paper is currently under review in Environment and Planning B. Please do not circulate without the authors' consent.

[†] Corresponding author: Health and Community Design Lab, School of Population and Public Health, University of British Columbia. (andyhong@gmail.com)

1. INTRODUCTION

Noise is one of the most hazardous environmental pollutants in urban areas (Berglund et al., 1999). A growing body of literature has reported a link between chronic exposure to noise and adverse effects on auditory health as well as psychological, behavioral, and physical health (Basner et al., 2014; Ising and Kruppa, 2004; Passchier-Vermeer and Passchier, 2000; Stansfeld et al., 2000). Because of these negative health impacts, environmental noise has emerged as one of the most important topics in public health (Hammer et al., 2013). Noise is also a common cause of neighbor disputes, potentially leading to verbal, psychological, and even physical conflicts between neighbors (The Atlantic, 2018). Popular media often portray noise pollution as one of the top urban issues causing public anger and frustration (Lovgreen, 2017; The Canadian Press, 2016).

Prior research on urban noise tends to focus on traffic noise, such as noise from vehicular traffic (Jakovljevic et al., 2009), aircraft (Lawton and Fujiwara, 2016), and railroads (Knall and Schuemer, 1983). Recio et al (2016) found that long-term as well as short-term road traffic noise is associated with cardiovascular, respiratory, and metabolic health. Orban et al (2016) also found that traffic noise in residential areas increases the risk of depressive symptoms. Pathak et al (2008) reported a significant association between traffic noise and negative impacts on daily activities, such as resting, reading, and communication. A number of studies have reported a relationship between airport noise and sleep disturbance (Basner et al., 2006), cardiovascular disease (Davies and Van Kamp, 2012; Eriksson et al., 2014; Jarup et al., 2005; Schmidt et al., 2013), and mental health (Beutel et al., 2016; Schreckenberg et al., 2010). Additionally, a small number of studies looked at the relationship between railroads and health impacts (Saremi et al., 2008; Sørensen et al., 2011). More broadly, noise annoyance has been negatively linked to self-reported health (Hammersen et al., 2016) and wellbeing (Shepherd et al., 2010).

Although traffic noise has been studied extensively, research on other sub-chronic noise pollutions, such as noise from nearby neighbors and construction activities, has been lacking. Especially in rapidly growing cities, one of the biggest noise annoyances in urban areas may come from construction activities (Ng, 2000). Construction, or more broadly speaking, urban development, is generally a sign of a healthy economy; however, rapid urban development may sometimes negatively impact human health, especially for the poor (Dye, 2008). From a classic environmental economics perspective, construction noise may be considered a negative externality, which is not fully internalized in most cost-benefit analysis frameworks (de Hollander and Staatsen, 2003).

Compared to consistent noise generated by traffic movement, frequency and levels of construction-related noise may change throughout the day, and therefore, are difficult to capture and quantify. For this reason, most research on noise pollution has typically focused on objective measurement, such as A-weighted sound pressure level (L_{Aeq}). However, the level of noise annoyance and disturbance may vary by people's characteritics (Belojević et al., 1997), and social and cultural factors (Hall et al., 2013). People may also perceive noise pollution differently depending their sensitivity to noise (Ohrström et al., 1988; Shepherd et al., 2010). However, few empirical research exist to date that examines perceived noise annoyance and disturbance due to construction activities prevalant in rapidly growing cities.

Given the paucity of research on perceived noise annoyance with respect to construction, this study investigates the relationship between construction and noise annoyance. Our analysis is based on crowdsourced noise complaints extracted from the 311 system that archives residents' service requests or complaints. The use of crowdsourced citizen complaint data as a proxy for noise annoyance is novel. To our knowledge, this is one of the first studies to empirically show adverse effects of urban development on neighborhood wellbeing with respect to noise. Our results imply that existing noise regulations may not be effective in restricting construction activities at night and during sleeping hours, and call for more stringent policies and regulations to ensure better qualtiy of life and wellbeing for urban residents.

3. METHODS

3.1. Study area

This study was conducted in the City of Vancouver, British Columbia, Canada. Vancouver is the eighth largest Canadian city with population of 631,486 (Statistics Canada, 2017) and one of the fastest growing cities in Canada. The number of building permits issued by the City and the construction values have been steadily increasing every year since 2011 (Figure S6). The average number of new permits issued is 5,731 cases per year, and the average construction value is about $2.18 billion (cdn.) per year. While more than half of these permits are for residential home development, around 20 to 30 cases per year since 2011 valued at $20 million (cdn.) or greater are very large construction projects (both commercial and residential development) (Province of British Columbia, 2017).

3.2. Crowdsourced noise complaints

The main outcome variable is noise complaints extracted from approximately two million geo-coded 311 service requests in the City of Vancouver from 2011 to 2016 (City of Vancouver, 2017b). The 311 system is a centralized a 24/7 non-emergency telephone service and online platform where residents can file complaints or requests on various issues. The 311 system records every instance of citizen reports which include date, time, request handling department and division, as well as case types and approximate location of the reporting individuals. Noise complaints account for about 2 to 3% of the entire service volume, while the most frequently reported cases are related to garbage and yard trimming pickups, and street tree and street light issues. In 2008, the City of Vancouver implemented a phone-based 311 system and launched VanConnect in 2015, an app that allows citizens to report complaints and submit service requests via their smart phones.

Noise complaints have been increasing steadily since 2011, and no apparent surge in number of reports has been identified after the implementation of the smartphone app in 2015 (Figure S6). Interestingly, after-hours noise complaints have accounted for more than 40% of all the noise complaints consistently throughout the year (Figure S6). This is notable because the City of Vancouver has had noise bylaws for more than three decades, aimed at limiting construction activities to restricted day-time hours. According to the City of Vancouver's Noise Control Bylaw 6555 (City of Vancouver, 2016), the permitted hours for construction activities are 7:30am - 8pm (Monday-Friday) and 10am - 8pm (Saturday) for private properties; and 7:30am -

8pm (Monday-Saturday) and 10am - 8pm (Sunday and holidays) for city streets. However, developers can bypass these restrictions by applying for a noise bylaw exception permit for a small fee ($165-329, cdn.).

Quality assurance of the crowdsourced 311 data

Because 311 data are relatively new in noise research, we examined the quality of the data to ensure that the data are a valid signal of noise annoyance. First, other complaints and service requests were compared against noise complaints, and only noise complaints showed a clear increasing pattern over time (Figure S1). This confirms that the trends observed in the noise complaints may not be driven by internal systematic changes in the 311 system or other secular trends that may endogenously affect noise complaints. Secondly, we checked to see if there were any instances of repeat submissions from the same address, e.g. super users. The data source could be subject to a "squeaky wheel" problem where excessive noise complaints come from a few people highly sensitive to noise, and these potential outliers may introduce bias in the data. However, close analysis of super users revealed that less than 1% of repeat noise complaints (> 5 times / month) came from the same addresses, and only four extreme cases from the same addresses (> 10 times / month) were identified (Figure S2). Also, our analysis results remained robust after removing these outliers from the sample. This suggests that our results are less likely to be influenced by a few outliers.

3.3. Major project inventory (MPI)

Our key predictor variable is the count of large-scale construction activities from 2011 to 2016 obtained from the major project inventory (MPI) database. The MPI database is maintained by the Province of British Columbia and includes a listing of both private and public sector construction projects with an estimated capital cost of $15 million (Cdn.) or greater. Within the lower mainland area, which includes our study area, the MPI captures construction projects that are valued at $20 million (Cdn.) or greater. For example, the major projects can range from as small as a 10-story condominium building to as big as a hospital redevelopment project. New projects are updated every quarter, and projects are removed from the list when they are completed or on hold for more than two years. For the purpose of our analysis, each project was coded as a dummy variable, with 1 indicating projects either started or are ongoing, and 0 indicating projects completed or on hold for each quarterly update.

3.4. Covariates

Census measures. As control variables, key demographic and socioeconomic characteristics were obtained from the Canada 2016 Census. Our unit of analysis is dissemination area, the smallest standard geographic area with a population of 400 to 700 persons defined by Statistics Canada. It is comparable to the U.S. Census block group. Typical demographic and socioeconomic controls were included in the final models, such as population size per dissemination area, proportion of children under 15 years, proportion of seniors over 65 years, proportion of houses rented, employment rate, and median household income.

Political participation. In addition to the demographic and socioeconomic controls, we further included voting rates as a proxy measure for political participation. Previous studies using data from constituent relationship management (CRM) system (e.g. 311 hotlines) have reported that there may be systematic biases in measurement due to some aspects of data collection, resulting in skewed reporting in the 311 system across neighborhoods (O'Brien et al., 2015, 2016; Offenhuber, 2015). For example, O'Brien and his colleagues (2016) have reported that civic activities and voting predicted a greater likelihood of reporting neighborhood disorder. To account for potential confounding effect of political participation, we used the most recent municipal election data from the City of Vancouver (2017a). Because voter turnout in local elections tends to be very low during non-federal elections, participation in municipal election has been regarded as an effective measure of political participation (Hajnal and Lewis, 2003; O'Brien et al., 2016). Figure S3 show the geographic distribution of municipal voting rates in 2017.

Number of proximate eating and drinking places. Another potential confounder of construction-related noise in urban areas includes proximity to noisy restaurants, bars, and nightclubs. Residents living in mixed use developments where shops and restaurants are collocated with residential units in the same building are particularly vulnerable to noise because these businesses are usually open until late at night. We used 2016 enhanced points of interest (EPOI) data from DMTI CanMap to extract businesses related to eating and drinking using Standard Industrial Classification (SIC) codes, 5812 and 5813 (Industry Group 581: Eating And Drinking Places) (DMTI, 2016). Geographic distribution of these businesses shows that they are mostly concentrated in downtown and along major corridors (Figure S4).

3.5. Analytical approach

Descriptive summary statistics and correlation analyses were performed using *t*-tests, χ^2 tests, and Pearson's correlation. For spatial analysis, heat maps were created using a kernel density estimation (KDE) to examine clustering patterns of the major construction and noise complaints over time. Generalized linear mixed effects models were developed to test the year fixed-effect and the effect of construction activity, while controlling for neighborhood-level random effects, with census dissemination area acting as neighborhoods (Eq. 1 in Suppl.). All the data points were spatially joined based on the census dissemination area (DA), which served as a random cluster variable. Noise complaints measures had Poisson distribution (Figure S5); therefore, a log-link function was used. For parameter estimation, maximum likelihood estimator and bootstrapped confidence interval were used. In order to check robustness of our results, additional regressions with the same specification were performed using only data of noise complaints reported during permitted and non-permitted hours. All analyses and mapping were performed using R version 3.4.2 (R Development Core Team, 2014).

4. RESULTS

4.1. Descriptive summary results

Table 1 provides a descriptive summary of the study measures. The average population density (people/km^2) per dissemination area (DA) was 5,964 (SD = 6,664). The gender was well balanced (female = 51%), and children (< 15 years) and seniors (> 65 years) accounted for 12% and 16%, respectively. About 44% of households were living in renter occupied dwelling units, and median household income was $72,811. In terms of other covariates, average voting rate per DA for the 2016 municipal election was 30%, and the average number of eating and drinking places was about 3 per DA in 2016.

INSERT TABLE 1 ABOUT HERE

For the key variables of interest, the average major construction activities per DA per quarter ranged between 0.63 and 0.83, and the total counts have increased 76% from 2011 to 2016 (Table S2). The average reports of noise complaints ranged between 1.33 and 1.48 per DA per month, and the total complaint volume has doubled from 2011 to 2016.

4.2. Spatio-temporal patterns of construction and noise complaints

Figure 1(a) illustrates the spatiotemporal patterns in major constructions in Vancouver. In 2011, major constructions were concentrated in the downtown area. The construction activities appear to have moved towards a southeast direction and along major commercial corridors, such as Cambie Street and Oak Street. Notably, construction activities near the University of British Columbia campus (far west) were consistent throughout time. Figure 1(b) shows the hotspots of where noise complaints have been reported. Similar to the construction activities, the downtown area has the highest volume of noise complaints. The noise complaints appear to move towards a southeast direction. The complaints also tend to concentrate along several mixed-use developments, such as Broadway and north of Cambie Street. These graphs show that both construction activities and noise complaints have been increasing and expanding along major corridors from 2011 to 2016.

INSERT FIGURE 1 ABOUT HERE

4.3. Mixed effects model results

Consistent with the general spatio-temporal patterns, models generally confirmed a positive relationship between major construction and noise complaints (Tables 2 and 3). Table 2 shows the model results using the full sample, and Table 3 shows the results using samples stratified by reporting time (permitted versus non-permitted noise hours) in the complaints data set. In the full sample model (Table 2), both year and major construction fixed effects were statistically significant at the 1% confidence level.

INSERT TABLE 2 ABOUT HERE

The final model results (Model 3 in Table 2) indicate that a one-unit increase in year is likely to increase monthly noise complaints by a factor of 1.074 or approximately 107%, accounting for demographic and housing-related factors (IRR = 1.074, 95% CI = 1.053–1.098). Similarly, a one-unit increase in quarterly construction activity is likely to increase monthly noise complaints by a factor of 1.059 or approximately 106%, while holding everything else in the model constant (IRR = 1.059, 95% CI = 1.026–1.093). To put this into a perspective, this means that 10 additional construction activities per quarter is associated with an increase of monthly noise complaints by 1.77 times or 177%. In the final model, both children and elderly population are negatively associated with noise complaints. For example, a one percent increase in the population 65 years and older is associated with a reduction in the number of noise complaints by a factor of 0.34 or 34%. The percentage of renter-occupied homes was also negatively related to noise complaints (Model 2), but the coefficient became statistically non-significant after adjusting for voting rate and number of proximate eating/drinking places (Model 3). The number of eating and drinking places was positively related to noise complaints but the effect size was very small (IRR = 1.005, 95% CI = 1.003–1.008). Interestingly, the association between voting rates and noise complaints was in a positive direction, but statistically insignificant.

Results of the models stratified by complaints made either during or after permitted noise hours (Table 3) were approximately the same as the full sample model. In Model 5 where the sample only included complaints during non-permitted hours (typically before 7:30 am or 10 am after 8 pm), the effect of construction activity strengthened from 1.059 (Model 3) to 1.064 (Model 5). This likely reflects there are many construction activities during non-permitted hours. The effect of proximate eating and drinking places attenuated from 1.005 to 1.004 (Model 4) and from

1.005 to 1.003 (Model 5), but the effects remained highly significant. Lastly, the association between voting rates and noise complaints was not statistically significant, suggesting that political participation may not be relevant in the context of reporting noise annoyance.

INSERT TABLE 3 ABOUT HERE

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5. DISCUSSION

Using the longitudinal administrative data from 2011 to 2016, this study found that construction activities were associated with higher volumes of noise complaints. The results suggest that a one-unit increase in construction activity was associated with approximately a 6% higher incidence rate of noise complaints. This is one of the first studies to empirically demonstrate the association between urban development and noise annoyance. It provides evidence that construction activities are associated with increases in noise complaints, and the current noise by-law in Vancouver may not be effective in protecting residents from exposure to construction-related noise at night and during sleeping hours. The results remained robust even after stratifying the analysis by reporting hours. The effect of construction activities attenuated slightly for complaints made during the normal permitted hours. However, the effect of construction was stronger for complaints made during the non-permitted hours, suggesting potential issues with the current noise control and regulatory framework.

The results also remained robust after adjusting for demographic and other covariates. Presence of proximate eating and drinking places was associated with noise complaints; however, voting rates were not significant. This suggests that noise reporting may not be politically driven and may operate through different reporting mechanisms than other complaints (e.g. graffiti removal) that are more driven by motivations for participating in government programs (O'Brien et al., 2016). For noise complaints, past work has shown self-motivation to reduce personal harms may be stronger than other motivations (Abu-Tayeh et al., 2018). In addition to our main findings, our study results imply that it will be necessary to understand the contribution of self-interests versus public interests when using crowdsourcing and social media platforms in the context of emerging smart cities and open governance framework (Linders, 2012).

Our finding is consistent with previous studies of traffic- and construction-related noise. A large body of work has reported a significant adverse impact of traffic noise on a variety of measures, such as subjective annoyance (Michaud et al., 2005), daily activities (Pathak et al., 2008), stress levels (Beutel et al., 2016; Schreckenberg et al., 2010), and sleep quality (Basner et al., 2006). Although few studies exist to date that directly examined the effect of construction on noise annoyance for residents, several studies have reported adverse social and economic impacts of construction, leading to delays and additional costs (Gilchrist and Allouche, 2005; Matthews et al., 2015; Zou et al., 2007). One study has reported that students living in a college dorm close to construction sites were distracted more frequently than those living farther away (Ng, 2000). Another study has reported that construction activities were directly responsible for high levels of annoyance by residents (Golmohammadi et al., 2013). Our study resonates with findings of these earlier studies in that, of many factors contributing to noise annoyance, construction activities can be a significant source of perceived annoyance by urban residents.

Finally, this study provides evidence that construction noise has far reaching impacts on the general population that go beyond those experienced by workers in occupational settings. In the United States and Canada, occupational health and safety regulations provide more stringent and direct mechanisms for limiting construction-related noise at worksites. Currently, Canadian Centre for Occupational Health and Safety (CCOHS) has established occupational exposure limits for noise at worksites. For example, in British Columbia, Canada, the steady noise level permitted for a full eight-hour shift is 85 dB(A) (Canadian Centre for Occupational Health and Safety, 2018). Previous research on occupational health and hygiene have reported negative impacts of construction noise on workers' health (Fernández et al., 2009; Golmohammadi et al., 2013; Lee et al., 2015; Li et al., 2016; Neitzel et al., 2011; Seixas et al., 2012; Xiao et al., 2016). A comprehensive review of construction-related noise studies has also reported that average daily noise exposure levels in most construction sites were usually above the permitted level (Suter, 2002).

In contrast with the extensive research on construction noise in occupational settings, potential health effect of construction noise on the general population has been limited, due to lack of available data on neighborhood noise and perceived annoyance. However, thanks to recent advances in 'big data' analytics (Mooney and Pejaver, 2018), it is now possible to use a vast array of new data sources linking traditional and non-traditional data to answer complex questions related to urban development pressures on population and environmental health (Vlahov et al., 2007; Zou et al., 2007). Through the novel use of crowdsourced noise complaints in conjunction with historical archives of major construction data, this study contributes to this emerging body of research using crowdsourced data to uncover noise-related health issues (Duncan et al., 2016; Tamura et al., 2017). Further research leveraging similar crowdsourced data through the 311 system readily available in many cities (Butterfield, 2006) will help inform future policies and programs aimed at monitoring and managing urban noise pollution.

Limitations and strengths

Despite its ability to provide new insights into a range of issues occurring throughout cities, 311 data have important limitations that must be considered. One limitation has to do with the fact that little is known about the demographics of the populations that use 311 services. If the population of 311 users does not reflect the broader population, there will be a bias in the information presented to governments. Similar issues are dealt with in research that utilizes social media data (e.g. Twitter data), where the sample of users is not considered to be representative of the broader population (Mislove et al., 2011; Smith and Brenner, 2012). A second limitation is that, unlike social media data, it is not possible to link 311 data back to individuals (Minkoff, 2016), making it difficult to know if certain users are disproportionately affecting the types and volume of calls being made through the service. This "squeaky wheel" problem is important, as a small number of highly motivated residents can lead to a large number of observations in the dataset. Although our data were not subject to such biases (Figure S2), the possibility of over-reporting in crowdsourced data may present some challenges in using them for real-time noise surveillance. However, the increasing popularity and availability of crowdsourced platforms will help make data collection processes more transparent and democratic, eventually leading to reducing biases in the data (Clark et al., 2016; Liu, 2017).

Lastly, it was assumed that the reporting time recorded in the 311 data represents relatively well the actual time of noise being heard and reported. However, there could be a time lag in the noise reporting process, which might have affected the model results stratified by reporting time. Even with these drawbacks, 311 data provide an additional data source that can be used to better understand the location and timing of issues faced by urban residents. As was done in the analysis presented in this paper, using 311 data to identify signals where there may be potential problems can be a useful first step that leads to local investigations, and ultimately, tangible shifts in policy.

Policy implications and takeaways

An important takeaway of this study is that construction-related noise can still persist at night and during sleeping hours even in the presence of noise limiting regulations and zoning codes. Although many large cities have noise by-laws, developers may get away with these regulations if the benefits of early completion far outweigh the costs associated with paying the noise by-law exemption fees. A cursory search of these exemptions in major cities in North America (U.S. and Canada) indicates that the exception fees typically range between \$0 and \$500 (Table S3). Because completing the project ahead of the schedule (or catching up after expensive delays) can significantly reduce construction costs (Meng and Gallagher, 2012), the additional costs of exemption fees may not be seen as a significant barrier to most developers. To our knowledge, no studies have directly examined the effectiveness of noise bylaws and exemption fee structures in controlling construction-related noise in urban areas. Future research should examine the effectiveness of various noise by-laws and abatement policies and whether exemption fees act as sufficient deterrents to after-hours construction activities that are more prone to generate noise problems in rapidly growing cities.

6. CONCLUSIONS

This study found associations of construction activities with noise complaints. It also provided evidence that after-hour noise complaints were positively related to major construction activities. These results imply that the existing noise by-laws may not be effective in restricting construction activities at night and during sleeping hours, which were found to have harmful effects on sleep quality and related health effects (Halperin, 2014; Hammer et al., 2013; Hume, 2010; Xiao et al., 2016; Zou et al., 2007). Although construction activities can be considered as a sign of a healthy economy (Garcia-Milà and McGuire, 1992; Glaeser et al., 2006), this study calls for deeper understanding of both positive and negative impacts of development on the quality of life and wellbeing of urban residents. Underestimation of potential negative impacts of urban development may help justify large construction projects, which could come at the expense of health and wellbeing of nearby residents and potentially vulnerable populations at greater health risks. Future studies should build on our findings to examine connections between urban development and perceived levels of noise pollution, ultimately linking actual health-related outcomes, including but not limited to, sleep deficiency, stress, and mental health.

Acknowledgement

This research was not supported by any funding. The authors would like to thank Grace Lee of the Government of British Columbia for her help in obtaining and understanding the major project inventory data. The authors would also like to thank Dr. Hugh Davies, and the audiences at the 2017 ACSP Conference and 2017 NARSC Conference for their valuable feedback. Widener would also like to acknowledge the support of the Canada Research Chairs program for supporting him with a Tier 2 Canada Research Chair in Transportation and Health.

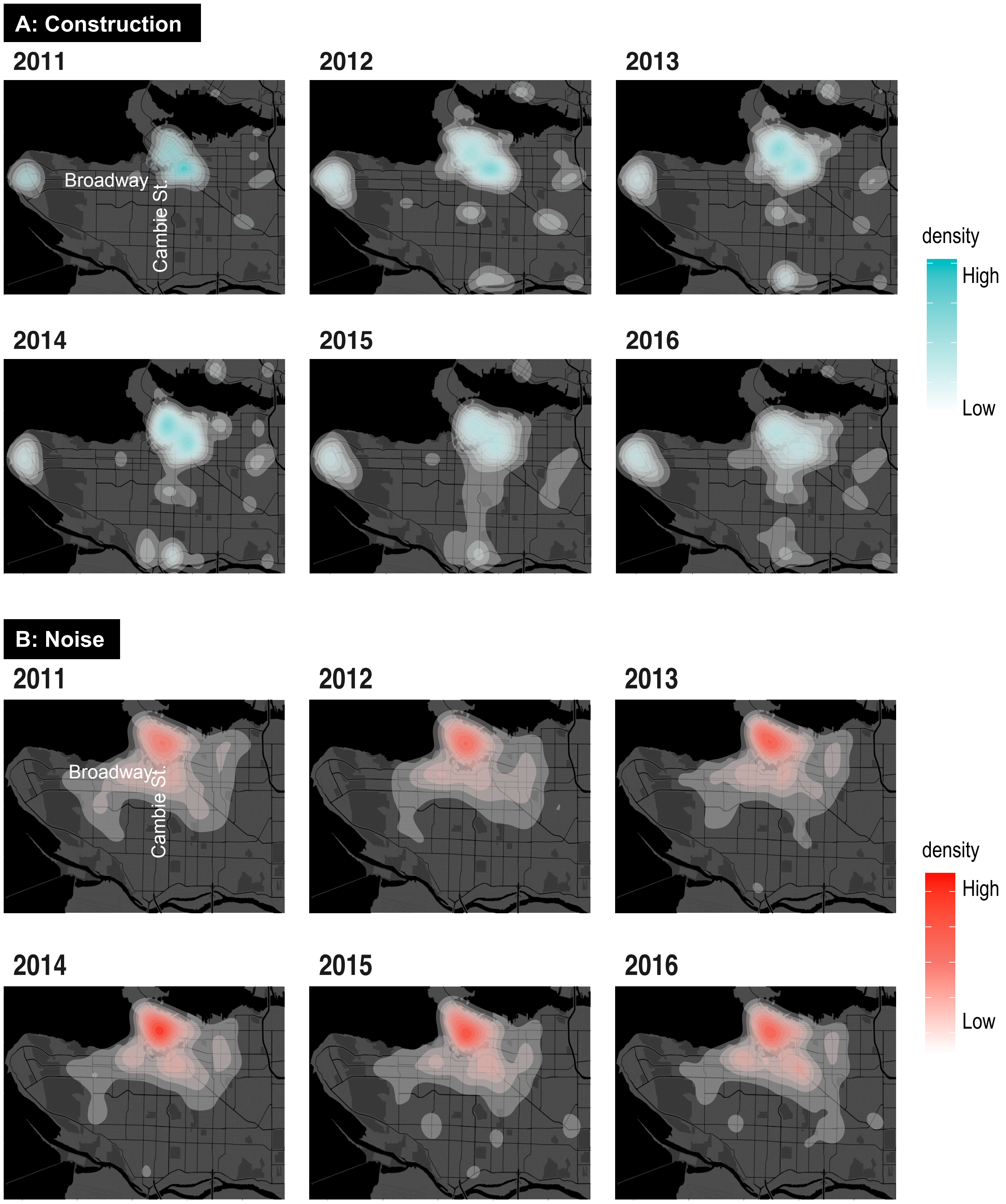

Figure 1. Spatio-temporal patterns of (a) major constructions and (b) noise complaints by year in Vancouver, Canada (2011-2016)

Table 1. Descriptive summary of demographic and covariate measures

Variables	Mean or % (SD) (N = 1,654)	Data sources
Demographics		
Population density (people/km^2)		Canadian Census 2016
Mean (SD)	5,964 (6,664)	
Missing	1	
Female population (% of total)		Canadian Census 2016
Mean (SD)	51% (4%)	
Missing	3	
Children < 15 years (% of total)		Canadian Census 2016
Mean (SD)	12% (5%)	
Missing	7	
Seniors > 65 years (% of total)		Canadian Census 2016
Mean (SD)	16% (8%)	
Missing	4	
Household-related measures		
Median household income		Canadian Census 2016
Mean (SD)	$72,811 ($24,926)	
Missing	4	
Percentage of renter-occupied homes		Canadian Census 2016
Mean (SD)	44% (22%)	
Missing	4	
Other covariates		
Voting rate	30% (5%)	2017 municipal election*
# of eating/drinking places	3.03 (9.04)	2016 DMTI EPOI*

Note: Unit of analysis is dissemination area (DA); *Data sources are 2016 Canadian Census, 2017 Municipal election results, and 2016 DMTI Enhanced Point of Interest data

Table 2. Associations of construction activities with all noise complaints in Vancouver, Canada (2011 – 2016)

	Dependent Variable: Noise complaints per month		
	Model 1	Model 2	Model 3
	IRR (95% CI)	IRR (95% CI)	IRR (95% CI)
Year	1.073*** (1.050, 1.095)	1.074*** (1.052, 1.097)	1.074*** (1.053, 1.098)
Major construction/quarter	1.071*** (1.031, 1.110)	1.067*** (1.029, 1.102)	1.059*** (1.026, 1.093)
Population density		1.000* (1.000, 1.000)	1.000 (1.000, 1.000)
% Female		1.008 (0.243, 3.631)	1.417 (0.431, 4.607)
% Children (< 15 yr)		0.021*** (0.004, 0.100)	0.117** (0.023, 0.721)
% Seniors (> 65 yr)		0.194*** (0.084, 0.426)	0.341*** (0.171, 0.708)
Median household income		1.000 (1.000, 1.000)	1.000 (1.000, 1.000)
% Renter occupied homes		0.596** (0.391, 0.942)	0.700 (0.470, 1.068)
Voting rate			1.034 (0.295, 3.039)
# of eating & drinking places			1.005*** (1.003, 1.008)
Random Effect			
# of DA	119	118	115
DA Variance	0.063	0.036	0.023
N	2020	2011	1996
Log Likelihood	-3054.32	-3024.854	-2995.51
AIC	6116.639	6069.708	6015.02
BIC	6139.083	6125.772	6082.207

Note: Of the 119 dissemination areas, there is 1 DA with unmatched sample in Model 2, leading to 9 missing in Model 2. There are 3 electoral divisions unmatched with DAs, which led to additional 15 missing in Model 3.
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3. Associations of construction activities with noise complaints during permitted and non-permitted hours in Vancouver, Canada (2011 – 2016)

	DV: Noise complaints during permitted hours	DV: Noise complaints during non-permitted hours
	Model 4	Model 5
	IRR (95% CI)	IRR (95% CI)
Year	1.063*** (1.035, 1.091)	1.046*** (1.015, 1.079)
Major construction/quarter	1.049*** (1.019, 1.075)	1.064*** (1.035, 1.095)
Population density	1.000 (1.000, 1.000)	1.000 (1.000, 1.000)
% Female	0.682 (0.180, 2.343)	1.606 (0.346, 6.032)
% Children (< 15 yr)	0.361 (0.054, 2.983)	0.135* (0.018, 1.143)
% Seniors (> 65 yr)	0.681 (0.288, 1.492)	0.445* (0.166, 1.031)
Median household income	1.000* (1.000, 1.000)	1.000 (1.000, 1.000)
% Renter occupied homes	1.068 (0.677, 1.745)	0.667 (0.398, 1.144)
Voting rate	1.188 (0.398, 3.467)	1.610 (0.419, 5.555)
# of eating & drinking places	1.004*** (1.002, 1.006)	1.003*** (1.001, 1.004)
Random Effect		
# of DA	113	112
DA Variance	0.003	0.003
N	1370	1055
Log Likelihood	-1818.927	-1407.668
AIC	3661.854	2839.336
BIC	3724.525	2898.872

Note: Of the 119 dissemination areas, there are 6 DAs and 7 DAs with unmatched sample in Models 4 and 5, respectively.
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

REFERENCES

Abu-Tayeh G, Neumann O, Stuermer M, 2018, "Exploring the Motives of Citizen Reporting Engagement: Self-Concern and Other-Orientation" *Business & Information Systems Engineering* **60**(3) 215–226

Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, Stansfeld S, 2014, "Auditory and non-auditory effects of noise on health" *The Lancet* **383**(9925) 1325–1332

Basner M, Samel A, Isermann U, 2006, "Aircraft noise effects on sleep: application of the results of a large polysomnographic field study" *The Journal of the Acoustical Society of America* **119**(5 Pt 1) 2772–84

Belojević G, Jakovljević B, Aleksić O, 1997, "Subjective reactions to traffic noise with regard to some personality traits" *Environment International* **23**(2) 221–226

Berglund B, Lindvall T, Schwela D H, 1999, "Guidelines for community noise"

Beutel M E, Jünger C, Klein E M, Wild P, Lackner K, Blettner M, Binder H, Michal M, Wiltink J, Brähler E, Münzel T, 2016, "Noise Annoyance Is Associated with Depression and Anxiety in the General Population- The Contribution of Aircraft Noise" *PloS one* **11**(5) e0155357

Butterfield E, 2006, "311 Systems Come of Age" *Washington Technology*

Canadian Centre for Occupational Health and Safety, 2018, "Noise - Occupational Exposure Limits in Canada" *OSH Answers Fact Sheets*, https://www.ccohs.ca/oshanswers/phys_agents/exposure_can.html

City of Vancouver, 2016, "Noise Control Bylaw 6555", Canada, http://former.vancouver.ca/bylaws/6555c.PDF

City of Vancouver, 2017a, "2017 By-election Municipal Election Official Results" *Municipal Elections*, http://data.vancouver.ca/datacatalogue/municipalElectionResults.htm

City of Vancouver, 2017b, "3–1–1 case location details" *Open data catalogue*, http://data.vancouver.ca/datacatalogue/311caseVolume.htm

Clark B Y, Zingale N, Logan J, Brudney J, 2016, "A Framework for Using Crowdsourcing in Government" *International Journal of Public Administration in the Digital Age* **3**(4) 57–75

Davies H, Van Kamp I, 2012, "Noise and cardiovascular disease: A review of the literature 2008-2011" *Noise {&} Health* **14**(61) 287

DMTI, 2016, "CanMap. Content Suite Data Dictionary 2016.3 Release"

Duncan D T, Tamura K, Regan S D, Athens J, Elbel B, Meline J, Al-Ajlouni Y A, Chaix B, 2016, "Quantifying Spatial Misclassification in Exposure to Noise Complaints Among Low-Income Housing Residents Across New York City Neighborhoods: A Global Positioning System (GPS) Study" *Annals of Epidemiology* **27**(1) 67–75

Dye C, 2008, "Health and Urban Living" *Science* **319**(5864) 766–769

Eriksson C, Hilding A, Pyko A, Bluhm G, Pershagen G, Östenson C-G, 2014, "Long-term aircraft noise exposure and body mass index, waist circumference, and type 2 diabetes: a prospective study" *Environmental health perspectives* **122**(7) 687–694

Fernández M D, Quintana S, Chavarría N, Ballesteros J A, 2009, "Noise exposure of workers of the construction sector" *Applied Acoustics* **70**(5) 753–760

Garcia-Milà T, McGuire T J, 1992, "The contribution of publicly provided inputs to states' economies" *Regional Science and Urban Economics* **22**(2) 229–241

Gilchrist A, Allouche E N, 2005, "Quantification of social costs associated with construction projects: state-of-the-art review" *Tunnelling and Underground Space Technology* **20**(1) 89–

104

Glaeser E L, Gyourko J, Saks R E, 2006, “Urban growth and housing supply” *Journal of Economic Geography* **6**(1) 71–89

Golmohammadi R, Mohammadi H, Bayat H, Habibi Mohraz M, Soltanian A R, 2013, “Noise annoyance due to construction worksites.” *Journal of research in health sciences* **13**(2) 201–7

Hajnal Z L, Lewis P G, 2003, “Municipal Institutions and Voter Turnout in Local Elections” *Urban Affairs Review* **38**(5) 645–668

Hall D A, Irwin A, Edmondson-Jones M, Phillips S, Poxon J E W, 2013, “An exploratory evaluation of perceptual, psychoacoustic and acoustical properties of urban soundscapes” *Applied Acoustics* **74**(2) 248–254

Halperin D, 2014, “Environmental noise and sleep disturbances: A threat to health?” *Sleep Science* **7**(4) 209–212

Hammer M S, Swinburn T K, Neitzel R L, 2013, “Environmental noise pollution in the United States: Developing an effective public health response” *Environmental Health Perspectives* **122**(2) 115–119

Hammersen F, Niemann H, Hoebel J, 2016, “Environmental noise annoyance and mental health in adults: Findings from the cross-sectional German health update (GEDA) study 2012” *International Journal of Environmental Research and Public Health* **13**(10) 1–12

de Hollander A E M, Staatsen B A M, 2003, “Health , environment and quality of life : an epidemiological perspective on urban development” *Landscape and Urban Planning* **65** 53–62

Hume K, 2010, “Sleep disturbance due to noise:Current issues and future research” *Noise and Health* **12**(47) 70

Ising H, Kruppa B, 2004, “Health effects caused by noise: evidence in the literature from the past 25 years” *Noise & health* **6**(22) 5–13

Jakovljevic B, Paunovic K, Belojevic G, 2009, “Road-traffic noise and factors influencing noise annoyance in an urban population” *Environment International* **35**(3) 552–556

Jarup L, Dudley M-L, Babisch W, Houthuijs D, Swart W, Pershagen G, Bluhm G, Katsouyanni K, Velonakis M, Cadum E, Vigna-Taglianti F, HYENA Consortium, 2005, “Hypertension and Exposure to Noise near Airports (HYENA): study design and noise exposure assessment” *Environmental health perspectives* **113**(11) 1473–8

Knall V, Schuemer R, 1983, “The differing annoyance levels of rail and road traffic noise” *Journal of Sound and Vibration* **87**(2) 321–326

Lawton R N, Fujiwara D, 2016, “Living with aircraft noise: Airport proximity, aviation noise and subjective wellbeing in England” *Transportation Research Part D: Transport and Environment* **42** 104–118

Lee S C, Hong J Y, Jeon J Y, 2015, “Effects of acoustic characteristics of combined construction noise on annoyance” *Building and Environment* **92** 657–667

Li X, Song Z, Wang T, Zheng Y, Ning X, 2016, “Health impacts of construction noise on workers: A quantitative assessment model based on exposure measurement” *Journal of Cleaner Production* **135** 721–731

Linders D, 2012, “From e-government to we-government: Defining a typology for citizen coproduction in the age of social media” *Government Information Quarterly* **29**(4) 446–454

Liu H K, 2017, “Crowdsourcing Government: Lessons from Multiple Disciplines” *Public Administration Review*

Lovgreen T, 2017, "'Just constant noise': residents upset over city-approved construction racket at 5 a.m." *CBC News*, http://www.cbc.ca/news/canada/british-columbia/overnight-construction-keeps-residents-up-1.4140335

Matthews J C, Allouche E N, Sterling R L, 2015, "Social cost impact assessment of pipeline infrastructure projects" *Environmental Impact Assessment Review* **50** 196–202

Meng X, Gallagher B, 2012, "The impact of incentive mechanisms on project performance" *International Journal of Project Management* **30**(3) 352–362

Michaud D, Keith S, McMurchy D, 2005, "Noise annoyance in Canada" *Noise & health* **7**(27) 39–47

Minkoff S L, 2016 *NYC 311: A Tract-Level Analysis of Citizen-Government Contacting in New York City*

Mislove A, Lehmann S, Ahn Y, Onnela J, Rosenquist J N, 2011, "Understanding the Demographics of Twitter Users", in *Proceedings of the Fifth International AAAI Conference on Weblogs and Social Media*, pp 554–557

Mooney S J, Pejaver V, 2018, "Big Data in Public Health: Terminology, Machine Learning, and Privacy" *Annual Review of Public Health* **39**(1) 95–112

Neitzel R L, Stover B, Seixas N S, 2011, "Longitudinal Assessment of Noise Exposure in a Cohort of Construction Workers" *The Annals of Occupational Hygiene* **55**(8) 906–916

Ng C F, 2000, "Effects of building construction noise on residents: A quasi-experiment" *Journal of Environmental Psychology* **20**(4) 375–385

O'Brien D T, Offenhuber D, Baldwin-Philippi J, Sands M, Gordon E, 2016, "Uncharted Territoriality in Coproduction: The Motivations for 311 Reporting" *Journal of Public Administration Research and Theory* **27**(2) 320–335

O'Brien D T, Sampson R J, Winship C, 2015, "Ecometrics in the Age of Big Data" *Sociological Methodology* **45**(1) 101–147

Offenhuber D, 2015, "Infrastructure legibility—a comparative analysis of open311-based citizen feedback systems" *Cambridge Journal of Regions, Economy and Society* **8**(1) 93–112

Ohrström E, Björkman M, Rylander R, 1988, "Noise annoyance with regard to neurophysiological sensitivity, subjective noise sensitivity and personality variables" *Psychological medicine* **18**(3) 605–13

Orban E, McDonald K, Sutcliffe R, Hoffmann B, Fuks K B, Dragano N, Viehmann A, Erbel R, Jöckel K-H, Pundt N, Moebus S, 2016, "Residential Road Traffic Noise and High Depressive Symptoms after Five Years of Follow-up: Results from the Heinz Nixdorf Recall Study" *Environmental health perspectives* **124**(5) 578–85

Passchier-Vermeer W, Passchier W F, 2000, "Noise exposure and public health" *Environmental health perspectives* **108 Suppl** 123–31

Pathak V, Tripathi B D, Mishra V kumar, 2008, "Evaluation of traffic noise pollution and attitudes of exposed individuals in working place" *Atmospheric Environment* **42**(16) 3892–3898

Province of British Columbia, 2017, "BC Major Projects Inventory", https://www2.gov.bc.ca/gov/content/employment-business/economic-development/industry/bc-major-projects-inventory/recent-reports

R Development Core Team, 2014, "A language and environment for statistical computing", http://www.r-project.org

Recio A, Linares C, Banegas J R, Díaz J, 2016, "Road traffic noise effects on cardiovascular, respiratory, and metabolic health: An integrative model of biological mechanisms"

Environmental Research **146** 359–370

Saremi M, Grenèche J, Bonnefond A, Rohmer O, Eschenlauer A, Tassi P, 2008, "Effects of nocturnal railway noise on sleep fragmentation in young and middle-aged subjects as a function of type of train and sound level" *International Journal of Psychophysiology* **70**(3) 184–191

Schmidt F P, Basner M, Kröger G, Weck S, Schnorbus B, Muttray A, Sariyar M, Binder H, Gori T, Warnholtz A, Münzel T, 2013, "Effect of nighttime aircraft noise exposure on endothelial function and stress hormone release in healthy adults" *European heart journal* **34**(45) 3508–14a

Schreckenberg D, Griefahn B, Meis M, 2010, "The associations between noise sensitivity, reported physical and mental health, perceived environmental quality, and noise annoyance" *Noise & health* **12**(46) 7–16

Seixas N S, Neitzel R, Stover B, Sheppard L, Feeney P, Mills D, Kujawa S, 2012, "10-Year prospective study of noise exposure and hearing damage among construction workers" *Occupational and Environmental Medicine* **69**(9) 643–650

Shepherd D, Welch D, Dirks K N, Mathews R, 2010, "Exploring the relationship between noise sensitivity, annoyance and health-related quality of life in a sample of adults exposed to environmental noise" *International Journal of Environmental Research and Public Health* **7**(10) 3579–3594

Smith A, Brenner J, 2012, "Twitter Use 2012", Washington, D.C

Sørensen M, Hvidberg M, Hoffmann B, Andersen Z J, Nordsborg R B, Lillelund K G, Jakobsen J, Tjønneland A, Overvad K, Raaschou-Nielsen O, 2011, "Exposure to road traffic and railway noise and associations with blood pressure and self-reported hypertension: a cohort study" *Environmental Health* **10**(1) 92

Stansfeld S A, Haines M M, Burr M, Berry B, Lercher P, 2000, "A Review of Environmental Noise and Mental Health." *Noise & health* **2**(8) 1–8

Statistics Canada, 2017, "Vancouver, CY [Census subdivision], British Columbia and Greater Vancouver, RD [Census division], British Columbia (table). Census Profile" *Statistics Canada Catalogue* No. 98-316-X2016001, https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E

Suter A H, 2002, "Construction Noise: Exposure, Effects, and the Potential for Remediation; A Review and Analysis" *AIHA Journal* **63**(6) 768–789

Tamura K, Elbel B, Chaix B, Regan S D, Al Y A, Jessica A, Julie K A, Duncan D T, 2017, "Residential and GPS-Defined Activity Space Neighborhood Noise Complaints , Body Mass Index and Blood Pressure Among Low- Income Housing Residents in New York City" *Journal of Community Health* **42**(5) 974–982

The Atlantic, 2018, "City Noise Might Be Making You Sick" *The Atlantic* (2/20/2018)

The Canadian Press, 2016, "New data shows nuisance noise prompts growing complaints across Vancouver" *The Canadian Press* (7/12/2016)

Vlahov D, Freudenberg N, Proietti F, Ompad D, Quinn A, Nandi V, Galea S, 2007, "Urban as a Determinant of Health" *Journal of Urban Health* **84**(S1) 16–26

Xiao J, Li X, Zhang Z, 2016, "DALY-Based Health Risk Assessment of Construction Noise in Beijing, China" *International Journal of Environmental Research and Public Health* **13**(11) 1045

Zou P X W, Zhang G, Wang J, 2007, "Understanding the key risks in construction projects in China" *International Journal of Project Management* **25**(6) 601–614