Noise and the City: Leveraging crowdsourced big data to examine the spatio-temporal relationship between urban development and noise annoyance[1]

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Abstract

Noise is one of the most frequent complaints and represents a public health hazard. While traffic-related noise has been studied extensively, research on construction noise has been lacking. In this study, we examined the relationship between construction activities and noise annoyance and tested whether this relationship is stronger after working-hours. Data were drawn from a historical inventory of major development projects and crowdsourced citizen complaints data (311 calls) in Vancouver, Canada from 2011 to 2016. Mixed effects models were developed with an interaction between construction activities and after-hours report. Results show that neighborhood noise complaints were significantly associated with major constructions (IRR = 1.062, 95% CI = 1.024–1.097). A significant interaction effect was also found between construction activities and after-hours reporting (IRR = 1.050 CI = 1.012–1.087). To our knowledge, this is one of the first studies to empirically show the adverse effects of urban development on noise annoyance. The results imply that existing noise bylaws may not be effective in restricting construction activities at night and during sleeping hours, which may cause adverse health effects.

Keywords: noise; annoyance; 311; big data; constituent relationship management (CRM); construction; crowdsourcing; smart cities

Highlights:

- Demonstrated a novel use of crowdsourced big data for noise research
- Construction activities were positively associated with noise complaints
- Construction's impact on noise annoyance may be stronger during after-hours
- Noise bylaws should be amended to restrict after-hours construction

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1. INTRODUCTION

Noise is one of the most hazardous environmental pollutants in urban areas. Studies have showned that approximately 40% of urban residents in the European Union are exposed to excessive noise (>55dB) daily (Berglund et al., 1999). In the United States, more than 100 million people have been exposed to noise that was high enough to introduce negative health outcomes (Simpson and Bruce, 1981; US EPA, 1981). 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 (Adams et al., 2006; Hammer et al., 2013; Wandersman and Nation, 1998). 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 levels (L_{Aeq}). However, the level of noise annoyance and disturbance may vary by people's characteristics (Belojević et al., 1997), social and cultural factors (Hall et al., 2013), and different times of day (Hoeger et al., 2002). People may also perceive noise pollution differently depending on their sensitivity to noise (Ohrström et al., 1988; Shepherd et al., 2010). However, few empirical studies exist to date that examines perceived noise annoyance and disturbance due to construction activities prevalent 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, and whether after-hours reporting moderates this relationship. 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 the adverse effects of urban development on perceived noise annoyance, which may be linked to successful urban planning and resident wellbeing (Shepherd et al., 2010).

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 a 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 S6a). 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, since 2011, around 20 to 30 cases per year, 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, 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 the number of reports was identified after the implementation of the smartphone app in 2015 (Figure S6b).

After-hours reporting

After-hours noise complaints have accounted for more than 40% of all the noise complaints consistently throughout the year (Figure S6b). 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 by-law exception permit for a small fee ($165-329, Cdn.). To test the effect of after-hours reporting, we created a dummy variable to indicate whether the noise complaints were recorded during after-hours. We then included the interaction term between the after-hours reporting and the construction activities in the mixed effects models.

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. Noise complaint data were extracted by classifying "Noise Complaint Case" and "General Noise Inquiry Case" in the "Case Type" column of the original 311 dataset. First, the total 311 call volumes were calculated by year, and other complaints and service requests were compared against noise complaints. The total volume of 311 cases increased over time, 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. These covariates are included to help explore whether dissemination areas with particular populations are more sensitive to noise annoyance. For example, dissemination areas with large portions of older or unemployed adults may have a larger number of potential reporters at home during times when construction activities are permitted.

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 calls) 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 the 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 elections 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). The geographic distribution of these businesses shows that they are mostly concentrated in downtown and along major corridors (Figure S4).

Residential exposure to transportation noise. To account for the effect of transportation noise, we included all transportation-related noise in the regression models. Detailed methods for estimating transportation noise have been described elsewhere (Gan et al, 2012). In brief, the noise prediction software CadnaA (Datakustik, Greifenberg, Germany) was used to estimate integrated transportation-related noise levels during the day, evening, and night in Vancouver for the year 2003. The data were based on estimated road traffic data, railway noise data, and aircraft noise data, and were calculated as annual day-evening-night A-weighted equivalent continuous noise levels (L_{den} dB(A)) for each area covered by a 6-digit postal code. The postal code-level data were then aggregated at the dissemination area level to be consistent with other datasets.

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.). We also tested the effect of after-hours by adding the interaction term between construction activities and after-hours reporting. Variables entered into the interaction term were centered at the mean of the distribution. 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 a Poisson distribution (Figure S5); therefore, a log-link function was used. For parameter estimation, a maximum likelihood estimator and bootstrapped confidence intervals were used. In order to check the 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, the 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. The average level of transportation-related noise per DA was about 63 dB(A) (SD = 3.85)

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*
Transportation-related noise (dB(A))	63.56 (3.85)	Gan et al, 2012

Note: Unit of analysis is dissemination area (DA); *Data sources are 2016 Canadian Census, 2017 Municipal election results, 2016 DMTI Enhanced Point of Interest data, and annual day-evening-night A-weighted equivalent continuous noise levels (Lden dB(A)) from Gan et al, 2012.

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 by 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 spatio-temporal patterns in major constructions in Vancouver. In 2011, major construction was 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.

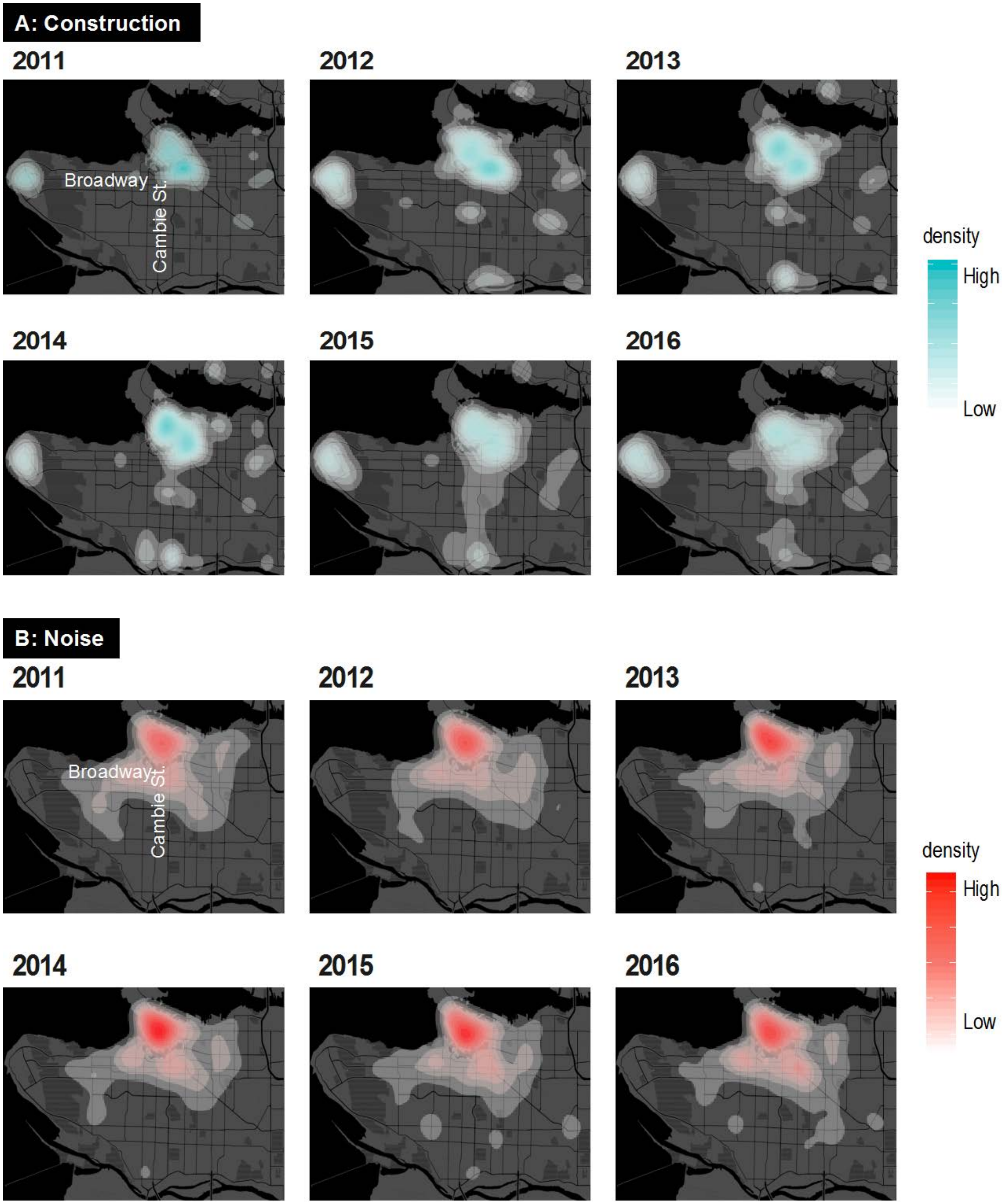

Figure 1. Spatio-temporal patterns of (a) major constructions and (b) noise complaints by year in Vancouver, Canada (2011-2016)

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. In Table 2, both year and major construction fixed effects were statistically significant at the 1% confidence level.

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

	Dependent Variable: Noise complaints			
	Model 1	Model 2	Model 3	Model 4
	IRR (95% CI)	IRR (95% CI)	IRR (95% CI)	IRR (95% CI)
Year	1.073*** (1.052, 1.096)	1.074*** (1.052, 1.098)	1.074*** (1.051, 1.098)	1.074*** (1.049, 1.098)
Major constructions	1.071*** (1.029, 1.105)	1.067*** (1.031, 1.099)	1.059*** (1.023, 1.091)	1.062*** (1.024, 1.097)
Population density		1.000* (1.000, 1.000)	1.000 (1.000, 1.000)	1.000 (1.000, 1.000)
% Female		1.008 (0.279, 4.157)	1.417 (0.421, 4.541)	1.527 (0.380, 5.086)
% Children (< 15 yr)		0.021*** (0.003, 0.128)	0.117** (0.020, 0.645)	0.151** (0.020, 0.838)
% Seniors (> 65 yr)		0.194*** (0.093, 0.407)	0.341*** (0.163, 0.663)	0.386** (0.184, 0.789)
Median household income		1.000 (1.000, 1.000)	1.000 (1.000, 1.000)	1.000 (1.000, 1.000)
% Renter occupied homes		0.596** (0.373, 0.943)	0.700 (0.456, 1.061)	0.718 (0.451, 1.165)
Voting rate			1.034 (0.335, 2.883)	1.178 (0.352, 3.598)
# of eating and drinking places			1.005*** (1.003, 1.008)	1.005*** (1.003, 1.007)
Transportation-related noise				1.014 (0.996, 1.032)
Random Effect				
# of Dissemination Area	119	118	115	114
Dissemination Area Variance	0.063	0.036	0.023	0.022
N	2,020	2,011	1,996	1,964
Log Likelihood	-3,054	-3,024	-2,996	-2,948
AIC	6,116	6,069	6,015	5,922
BIC	6,139	6,125	6,082	5,995

Note: Of the 119 dissemination areas, there is 1 dissemination area (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. There is 1 unmatched electoral division, resulted in 32 missing in Model 4.
S*ignificance levels*: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
IRR means Incidence Rate Ratio.

The final model results (Model 4 in Table 2) showed that a one-unit increase in a year resulted in a 7.4% increase in monthly noise, accounting for demographic and housing-related factors (Incidence rate ratio (IRR) = 1.074, 95% CI = 1.049–1.098). Similarly, a one-unit increase in construction activities resulted in a 6.2% increase in monthly noise, while holding everything else in the model constant (IRR = 1.062, 95% CI = 1.024–1.097).

Results of the interaction model (Table S3) showed that there is a moderation effect of after-hours report on the association of construction activities with noise complaints. In Table S3, both the main effects for construction activities (IRR = 1.031, 95% CI = 0.987–1.070) and after-hours reporting (IRR = 1.463, 95% CI = 1.339–1.586) were significant. The interaction term between construction activities and after-hours reporting was also highly significant (IRR = 1.050, 95% CI = 1.012–1.087). Figure 2 clearly shows this interaction effect. The effect of construction activities on noise complaints during after-hours appears to be stronger and increasing more exponentially than regular hours.

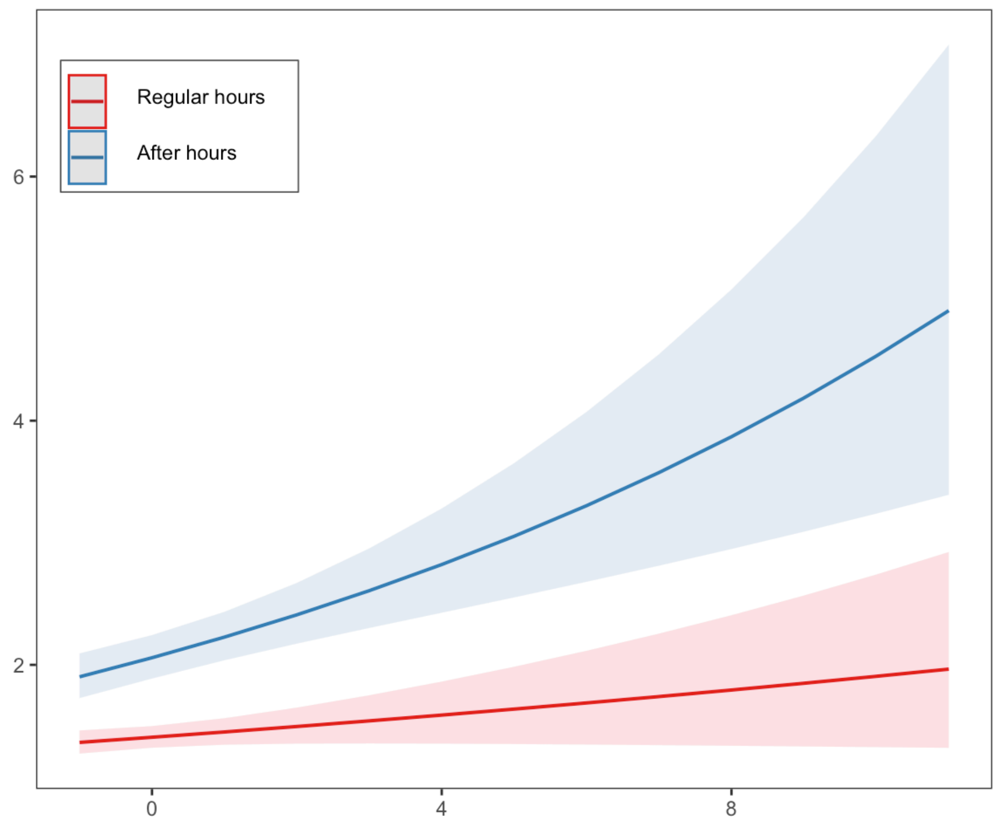

Figure 2. Effect of interaction between construction activities and after-hours reporting on noise complaints in Vancouver, Canada (2011 – 2016).

Note: The permitted (regular) hours for construction activities are: 7:30am - 8pm (M-F) and 10am - 8pm (Sa) for private properties; 7:30am - 8pm (M-Sa) and 10am - 8pm (Su & holidays) for city streets. The interaction effect was plotted by holding covariates constant at their mean values.

In terms of the covariates, both children and the 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 34% reduction in monthly noise complaints. The percentage of renter-occupied homes was also negatively related to noise complaints (Model 2 in Table 2), but the coefficient became statistically non-significant after adjusting for voting rate and number of proximate eating/drinking places (Model 3 in Table 2). The number of eating and drinking places was positively related to noise complaints, but the effect size was very small (Model 4, IRR = 1.005, 95% CI = 1.003–1.007). Interestingly, the association between voting rates and noise complaints was in a positive direction, but statistically insignificant. No significant relationship was found between transportation-related noise and noise complaints.

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 an approximately 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. Furthermore, the significant interaction effect of construction activities and after-hours reporting implies potential issues with the current noise control and regulatory framework. The main effect of construction activities attenuated slightly when the interaction term was included in the model. However, the effect of construction activities on noise complaints seems to be stronger during after-hours than regular hours. This suggests that people are more disturbed at night due to construction activities, and that the current noise by-law in Vancouver may not be effective in protecting residents from exposure to construction noise during sleeping hours.

The results remained robust after adjusting for demographic and other covariates. The presence of proximate eating and drinking places was associated with noise complaints; however, voting rates and transportation-related noise were not significant. This suggests that transportation-related noise may not be a strong enough driver to invoke noise complaints. In a similar vein, the results suggest 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 that self-motivation to reduce personal harm may be stronger than other motivations (Abu-Tayeh et al., 2018). However, this statement is complicated by other research that has shown that those who are economically dependent upon the noise source are less likely to report an annoyance (Miedema and Vos, 1999). More work on this aspect of noise annoyance reporting is warranted. In addition to our main findings, our 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 frameworks (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 have 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 the 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, the 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, the 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). For example, low cost sensors are now available for collecting granular noise data in real time, and such new data sources will likely transform our understanding of how noise is generated and will change the way we manage urban noise problem in the 21st century (Park et al., 2014). 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, 311 data have important limitations that must be considered. One limitation is related to the use of noise complaints as a measure of noise annoyance. It is possible that noise complaints only represent the extreme case of noise annoyance. More work would be needed to determine how well noise complaints are correlated with noise annoyance using a more traditional measure (International Organization for Standardization, 2003). Another 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 third 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 the actual time of noise being heard and reported relatively well. 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 could be more serious at night and during sleeping hours even in the presence of noise limiting regulations and zoning codes. The seriousness of after-hours construction noise was also confirmed by a recent New York City study, where the actual noise sensor data provided quantitative evidence for 94% of all after-hours construction complaints (Bello et al., 2018). 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 S4). 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 generating noise problems in rapidly growing cities.

6. CONCLUSIONS

This study found associations between construction activities and noise complaints. It also provided evidence that the impact of construction activities on noise complaints may be stronger during after-hours than regular hours. 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 aspects 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.

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