

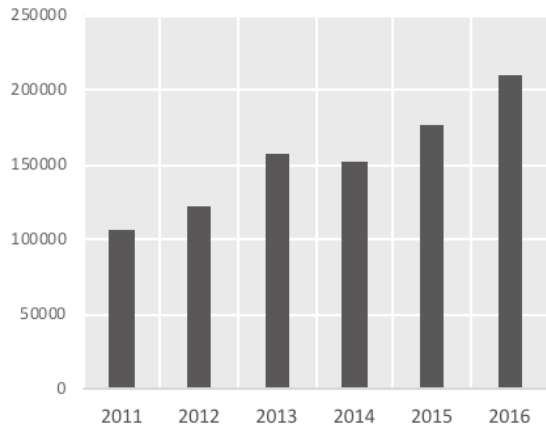
Supplementary Material

Noise and the City: Leveraging crowd-sourced big data to examine the spatio-temporal relationship between urban development and noise annoyance

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1. Validity of the crowdsourced noise data extracted from the 311 system

1.1 Total 311 Call Volume by Year



1.2 Comparison with other complaints/service requests

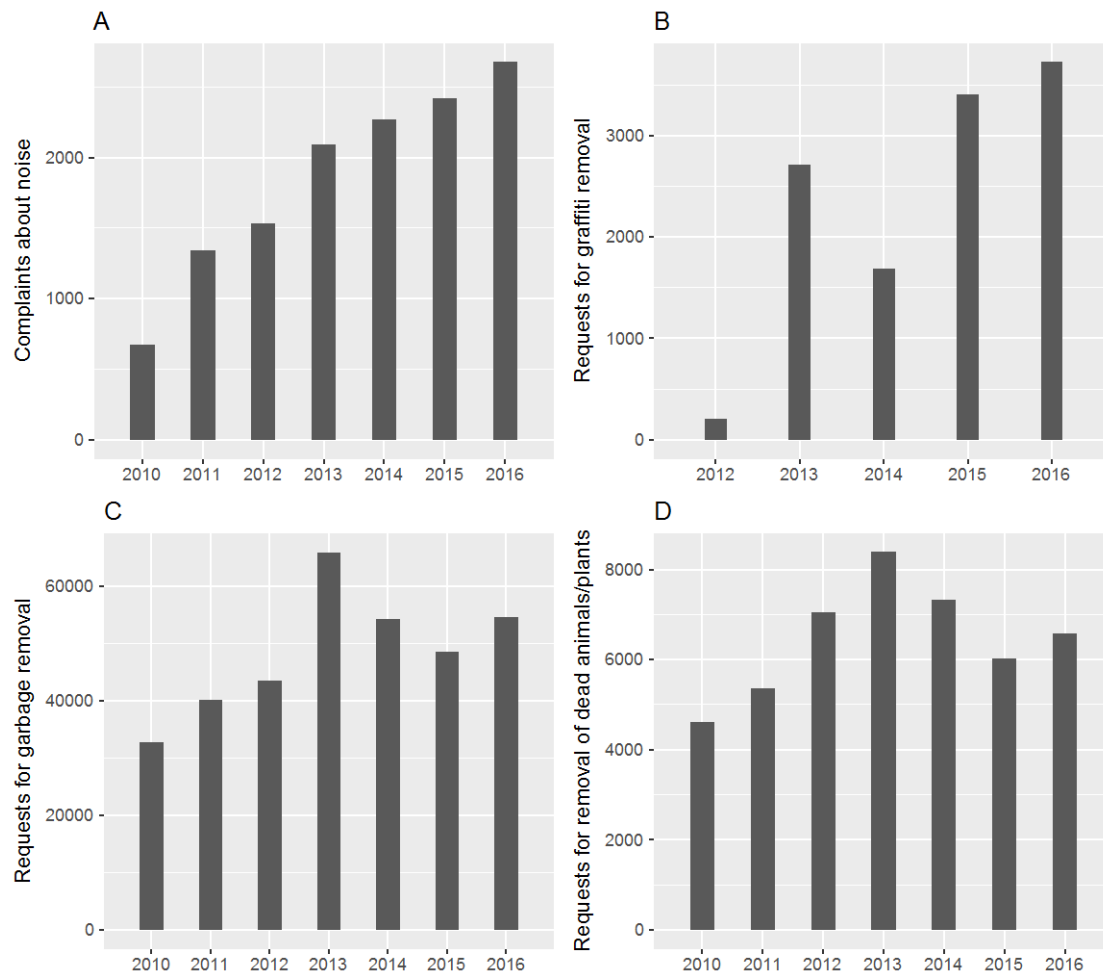


Figure S1. Temporal patterns of various complaints/service requests: a) noise complaints; b) requests for graffiti removal; c) requests for garbage removal; d) requests for removal of dead animals and plants

1.2. Analysis of super users

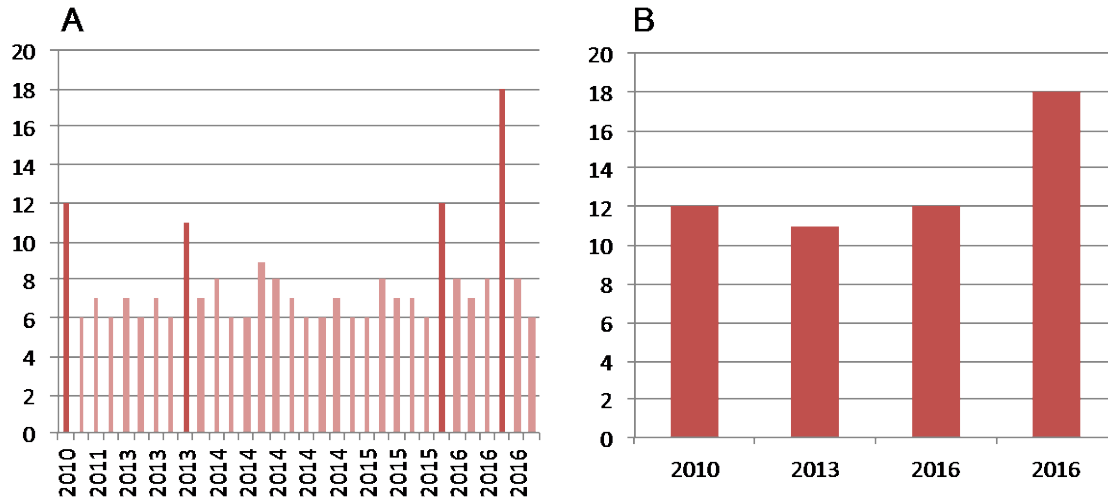


Figure S2. Analysis of super users: a) more than 5 repeat complaints/service requests from the same address; b) more than 10 repeat complaints/service requests from the same address

2. Potential confounders of noise complaints

2.1. Political participation

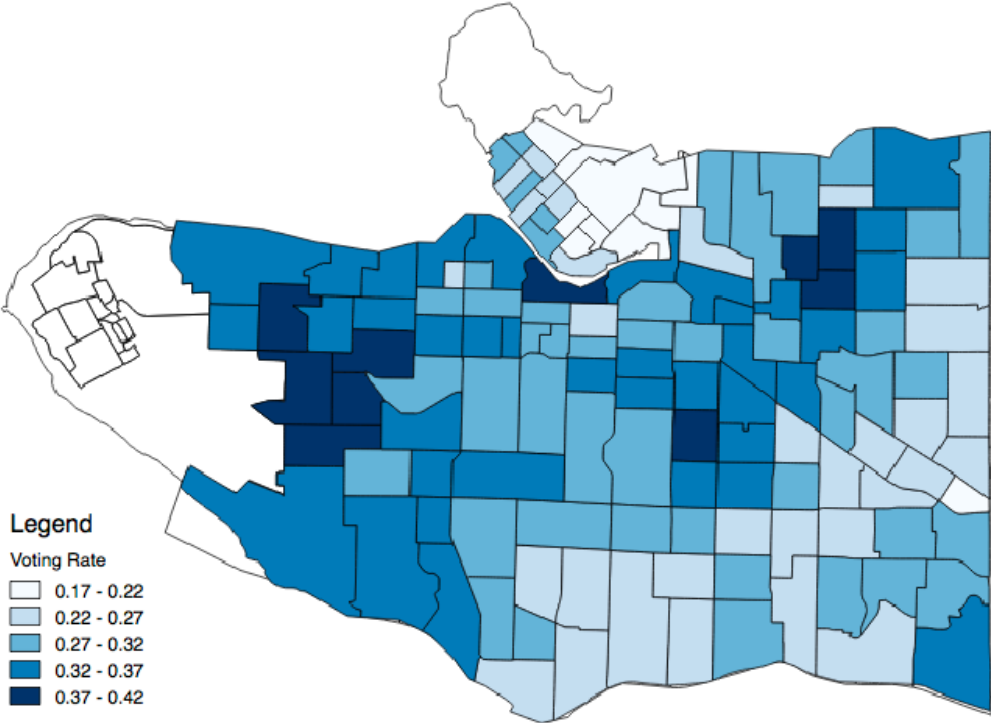


Figure S3. Geographic distribution of municipal voting results in 2017
Source: City of Vancouver (2017a)

2.2. Eating and drinking places

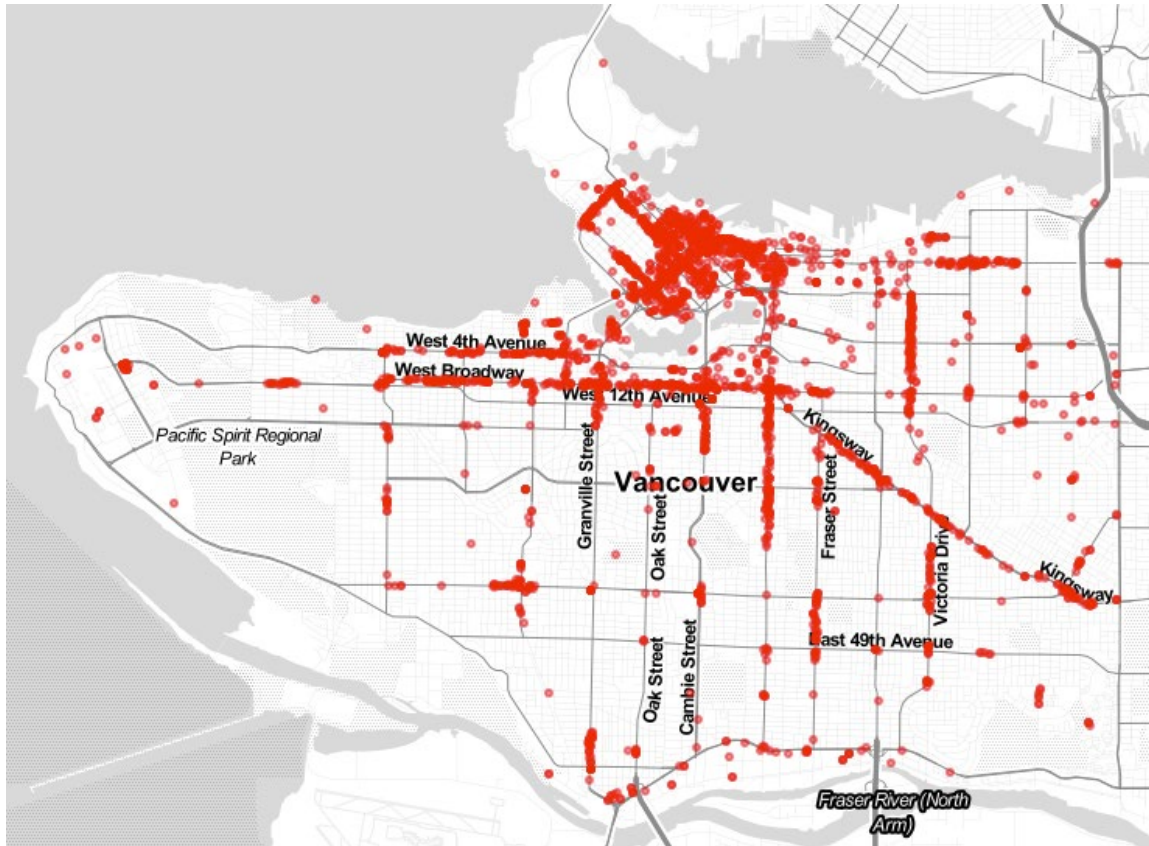


Figure S4. Geographic distribution of eating and drinking places in Vancouver in 2016.
Source: DMTI (2016)

3. Mixed effect model formulation and diagnostics

3.1. Model formulation

The functional form of the mixed effect model is as follows:

$$y_{ij} \sim \text{Poisson}(\mu_{ij})$$

$$\text{Level 1: } \log(\mu_{ij}) = \beta_{0j} + \beta_1 x_{1ij} + \beta_2 x_{2ij} + \beta_3 x_{3ij} + \beta_4 (x_{2ij} \times x_{3ij}) + \beta_5 x_{5ij} + \dots + \beta_n x_{nij} + \varepsilon_{ij}$$

$$\text{Level 2: } \beta_{0j} = \beta_0 + u_{0j}$$

$$\varepsilon_{ij} \sim N(0, \sigma^2), \quad u_{0j} \sim N(0, \tau^2), \quad (\text{Eq. 1})$$

where y_{ij} is the i -th observation of noise complaints per quarter in the j -th dissemination area; β_{0j} is the estimated mean for the j -th dissemination area. β_1, β_2 and β_3 denote individual fixed-effects estimators for year, quarterly construction activities, and after-hours for the j -th dissemination area. B_4 denotes an interaction effect between construction activities and after-hours. B_5 through β_n represent fixed-effects covariates, including demographic and socioeconomic controls, political participation, the number of proximate eating and drinking places, and transportation-related noise levels.

3.2. Model diagnostics

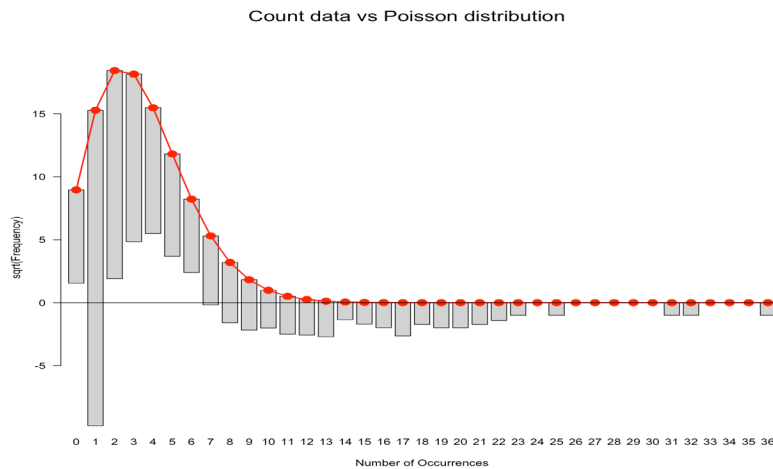


Figure S5. Distribution of noise complaints (2011-2016)

Table S1. Comparison of linear model and Poisson model

Linear model		Poisson model	
Diagnostics	Values	Diagnostics	Values
Mean	2.71	Chisq	1605
Var	9.76	RDF	1281
Ratio	3.60	Ratio	1.2529274

4. Historical trends and descriptive summary of construction and noise complaints

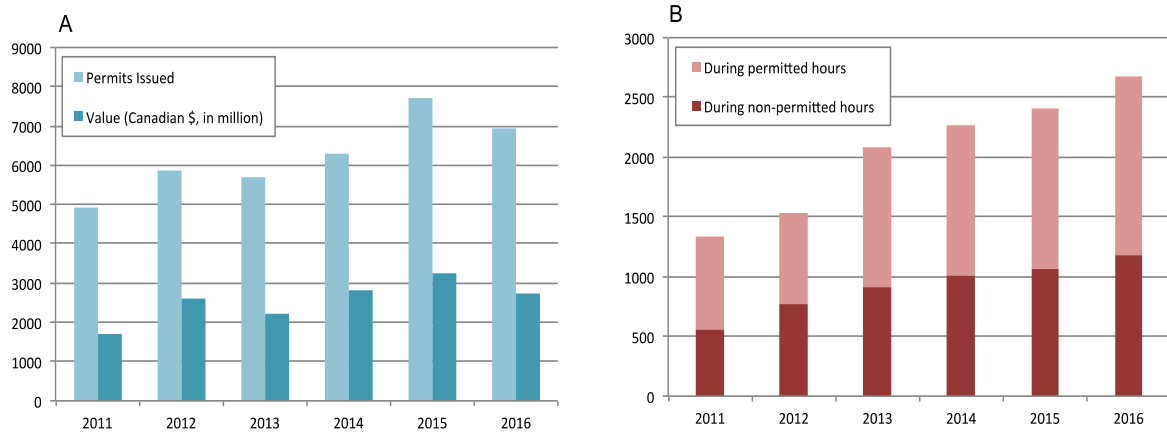


Figure S6. a) Issued building permits and construction values for Vancouver, Canada (2011 – 2016); b) Noise complaints (during permitted and non-permitted hours) from the 311 call data for Vancouver, Canada (2011 – 2016)

Note: The permitted hours for construction activities are defined as 7:30am - 8pm (Mon-Fri) and 10am - 8pm (Sat) for private properties; and 7:30am - 8pm (Mon-Sat) and 10am - 8pm (Sun & holidays) for city streets (City of Vancouver, 2016). Data come from: (a) City of Vancouver (City of Vancouver, 2018); (b) City of Vancouver (City of Vancouver, 2017b)

Table S2. Descriptive summary of key variables of interest (2011 – 2016)

Year	Major construction		Noise complaints	
	Mean (SD) [†]	Total	Mean (SD) [‡]	Total
2011	0.63 (1.19)	194	1.39 (0.97)	1,340
2012	0.83 (2.09)	196	1.33 (0.83)	1,530
2013	0.80 (2.04)	270	1.33 (0.83)	2,089
2014	0.82 (1.89)	284	1.42 (1.02)	2,264
2015	0.82 (1.77)	305	1.48 (1.24)	2,410
2016	0.72 (1.21)	255	1.46 (1.12)	2,671

Note: [†] Average quarterly construction projects per dissemination area per year; [‡] Average monthly noise complaints per dissemination area per year

5. Interaction model results

Table S3. Associations of construction activities with noise complaints during permitted and non-permitted hours in Vancouver, Canada (2011 – 2016)

	Dependent Variable: Noise complaints	
	Model 5	Model 6
	IRR (95% CI)	IRR (95% CI)
Year	1.063*** (1.041, 1.090)	1.064*** (1.042, 1.089)
Major constructions	1.059*** (1.018, 1.095)	1.031* (0.987, 1.070)
After hours	1.528*** (1.408, 1.649)	1.463*** (1.339, 1.586)
Major constructions X After hours		1.050*** (1.012, 1.087)
Population density	1.000 (1.000, 1.000)	1.000 (1.000, 1.000)
% Female	1.228 (0.396, 4.140)	1.253 (0.371, 4.157)
% Children (< 15 yr)	0.170** (0.028, 1.062)	0.169** (0.025, 0.881)
% Seniors (> 65 yr)	0.383*** (0.179, 0.746)	0.379*** (0.191, 0.715)
Median household income	1.000 (1.000, 1.000)	1.000 (1.000, 1.000)
% Renter occupied homes	0.811 (0.533, 1.189)	0.799 (0.545, 1.213)
Voting rate	1.249 (0.444, 3.652)	1.210 (0.444, 3.624)
# of eating and drinking places	1.005*** (1.003, 1.007)	1.005*** (1.003, 1.007)
Transportation-related noise	1.012 (0.993, 1.028)	1.013 (0.996, 1.029)
Random Effect		
# of Dissemination Area	114	114
Dissemination Area Variance	0.017	0.017
N	1,964	1,964
Log Likelihood	-2,888.65	-2,882.11
AIC	5,805.30	5,794.21
BIC	5,883.45	5,877.96

Note: Of the 119 dissemination areas, there are 5 Dissemination Areas (DAs) with unmatched sample in Models 4 and 5.

Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

IRR means Incidence Rate Ratio.

6. Comparison of noise exemptions across North American cities

Table S4. A list of North American cities with noise exemptions

City	Permitted hours	Noise exemption fee	Exemption conditions	Municipal codes (Source)
City of New York	7am – 6pm (M-F)	\$100-\$500 (USD) application fee and \$80 daily fee	Construction activity before 7:00 am, after 6:00 pm, or on the Weekend and approved Noise Mitigation Plan	Title 15 Rules of the City of New York (RCNY) Chapter 28, Local Law 113
City of San Francisco	7am – 8pm	\$123 (USD)	No high-impact and/or pneumatic tools and equipment. No excavation work. Noise level no more than 10 dBA above the local ambient.	San Francisco Police Code Article 29
City of Los Angeles	7am – 9pm (M-F) 8am – 6pm (Sa, holidays) No construction except for residents (Su)	Application fee \$248 (USD)	Under written permission of the Board of Police Commissioners through its Executive Director	City of Los Angeles Municipal Code, Section 41.10
City of Houston	7am – 10pm	\$68.41 (USD) (Extended daily permit.)	Any loudspeaker, sound amplifier or any other machine or device which produces applicable dB(A) levels.	City of Houston Municipal Code, Section 30
City of Chicago	8am – 8pm	N/A	Emergency nature or to work on public improvements authorized by a governmental body or agency.	City of Chicago Municipal Code, Section 8-32-140
City of Vancouver	Private properties: 7:30am - 8pm (M-F), 10am-8pm (Sa); City streets: 7:30am - 8pm (M-Sa), 10am - 8pm (Su & holidays)	\$165-\$329 (CAD)	Construction activities needing to extend beyond the permitted hours	Noise Control Bylaw 6555
City of Toronto	7am - 7pm (M-F); 9am - 7pm (Sa)	\$100 (CAD)	Special events; events in parks; construction that extends beyond permitted hours	Toronto Municipal Code Chapter 591, Noise
City of Calgary	7am - 10pm (M-Sa); 9am - 10pm (Su & holidays)	N/A	Any events, including construction, expected to exceed the permitted noise levels	Community Standards Bylaw 5M2004
City of Ottawa	Residential neighborhoods: 7am - 8pm (M-F), 9am - 7pm (Weekends & holidays); Any structure, highway or building: 7am - 10pm (M-Sa), 9am - 10pm (Su & holidays)	\$50 (CAD)	Construction noise not exceeding 85 dBA; duration of exemption not exceeding 11 days	Noise By-Law 2017-255

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