Project 003 Cardiovascular Disease and Aircraft Noise Exposure

Boston University

Project Lead Investigator

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University Participants

Boston University (BU)

- PIs: Prof. Jonathan Levy (University PI), Prof. Junenette Peters (Project PI)
- FAA Award Number: 13-C-AJFE-BU-016
- Period of Performance: October 1, 2019 to September 30, 2020

Massachusetts Institute of Technology (MIT)

- Sub-PI and Co-I: Prof. R. John Hansman, Dr. Florian Allroggen

Tasks (Performance Period)

Related to 2018 FAA Reauthorization, Section 189, Tasks 1–3

1. Generate final results for analyses of hypertension and aircraft noise exposure.
2. Generate preliminary results of supporting analyses.
   a. Trends of aircraft noise exposure.
   b. Sociodemographic patterning of aircraft noise exposure.
3. Assess suitability of existing cohort data on sleep quality and develop a noise-sleep analysis plan.
4. Develop an analysis plan for cardiovascular disease (CVD) and aircraft noise exposure and generate descriptive statistics.

Related to 2018 FAA Reauthorization, Section 189, Task 4

5. Develop a model for measuring change in business activities attributable to aircraft noise exposure prototyping a model city.

Project Funding Level

Total funding (three-year funding): $1,729,286
Matching: $1,729,286
Source of matching funds: Nonfederal donors to the Nurses' Health Study (NHS), Health Professional Follow-up Study (HPFS), and Women's Health Initiative (WHI) cohorts.

Investigation Team

Junenette Peters, PI, Boston University
Dr. Peters is responsible for directing all aspects of the proposed study, including study coordination, design and analysis plans, and co-investigator meetings.

Jonathan Levy, Boston University
Dr. Levy will participate in noise exposure assessment and provide expertise in the area of predictive modeling and air pollution.

Francine Laden, Jaime Hart, and Susan Redline, Harvard Medical School/Brigham and Women's Hospital
Dr. Laden is our NHS and HPFS sponsor for this ancillary study. Dr. Hart will assign aircraft noise exposures to the geocoded address history coordinates of each cohort member. Dr. Laden and Dr. Hart will also assist in documenting data from the NHS and HPFS based on their previous experience in air pollution and chronic disease outcome research in these cohorts and in appropriate analyses of hypertension and cardiovascular outcomes. Dr. Redline will lead efforts related to noise and sleep disturbance in the NHS and WHI.

John Hansman and Florian Allroggen, Massachusetts Institute of Technology
Dr. Hansman will participate in the economic impact assessment and will provide expertise on analytical approaches for quantifying noise. Dr. Allroggen will perform an economic impact assessment based on his expertise in analyzing the societal costs and benefits of aviation.

Project Overview
Exposure to aircraft noise is considered the most significant perceived environmental impact of aviation in communities surrounding airports (Wolfe et al., 2014). Exposure to aircraft noise has been associated with physiological responses and psychological reactions (Bluhm & Eriksson, 2011; Hatfield et al., 2001), including sleep disturbances, sleep-disordered breathing, nervousness, and annoyance (Hatfield et al., 2001; Rosenlund et al., 2001). Recent literature, primarily from European studies, provides evidence of a relationship between aircraft noise and self-reported hypertension (Rosenlund et al., 2001), increased blood pressure (Evrard et al., 2017; Haralabidis et al., 2008; Haralabidis et al., 2011; Jarup et al., 2008; Matsui et al., 2004), antihypertensive medication use (Bluhm & Eriksson, 2011; Floud et al., 2011; Franssen et al., 2004; Greiser et al., 2007), and incidence of hypertension (Dimakopoulou et al., 2017; Eriksson et al., 2010). However, the extent to which aircraft noise exposure increases the risk of adverse health outcomes is not well understood. Impacts related to annoyance have been empirically studied using the stated preference approach (Bristow et al., 2015) and the revealed preference approach, which often relies on analyses of house prices (Almer et al., 2017; Kopsch, 2016; Wadud, 2013). Although the impacts of aircraft noise on individuals are well understood, little evidence has been presented on the impact of aircraft noise exposure on companies located beneath flight paths. Section 189 of the 2018 FAA Authorization has called for a study on the potential health and economic impacts attributable to aircraft overflight noise.

The goal of this ongoing project is to examine the potential health impacts attributable to noise exposure resulting from aircraft flights, and this project will leverage ongoing work within ASCENT to respond to Section 189. This study aims to assess the potential association between aircraft noise exposure and outcomes such as sleep disturbance and elevated blood pressure. The study will leverage existing collaborations with well-recognized and respected studies that have followed over 250,000 participants through the course of their lives to understand factors that affect health. These studies include the NHS and HPFS. Furthermore, this work is aligned with an ongoing National Institutes of Health (NIH)-funded effort to examine these associations in the WHI. The research team will leverage aircraft noise data for 90 U.S. airports from 1995–2015, as generated using the Aviation Environmental Design Tool (AEDT); these data will then be linked to demographic, lifestyle, and health data for the participants of long-term health studies. These studies provide considerable geographic coverage of the United States, including all the geographic areas specified in Section 189.

This work will also respond to the aspect of Section 189 calling for the study of economic harm or benefits for businesses located underneath regular flight paths. The study will involve a first-of-its-kind empirical assessment of the economic impacts on businesses located beneath flight paths at selected U.S. airports. Such impacts are expected to be driven by (a) potential positive economic impacts related to the airport and its connectivity and (b) environmental impacts such as noise, which may reduce the revenue and productivity of businesses beneath flight paths. The team will evaluate whether such impacts can be empirically identified while considering economic outcome metrics such as the gross domestic product (GDP), employment, and revenue.

The overall aims for the three-year project are as follows:
- Perform Tasks 1–3 [*Sec. 189. (b)(1–3)*]: Potential health impacts attributable to aircraft overflight noise.
    - Investigate the relationship between aircraft noise exposure and the incidence of hypertension in the NHS and HPFS, accounting for other individual- and area-level risk factors.

   - Investigate the relationship between aircraft noise exposure and the incidence of cardiovascular disease (CVD) in the NHS and HPFS cohorts and determine whether sufficient data exist to prove a causal relationship.
   - Determine whether a relationship exists between annual average aircraft noise exposure and general sleep length and quality in the NHS and the Growing Up Today Study (GUTS) and report whether sufficient data exist to prove a causal relationship.
   - Evaluate the potential relationship between residing under a flight path and measures of disturbed sleep in the WHI WHISPER sub-study.
- Perform Task 4 [*Sec. 189. (b)(5)*]: Potential economic impacts attributable to aircraft overflight noise.
   - Model noise exposure before and after the introduction of area navigation (RNAV) procedures on the basis of FAA flight trajectory data.
   - Combine noise data with yearly county-level data from the Bureau of Economic Analysis (BEA) (e.g., GDP, employment) and with city-level statistics for the years 2007, 2012, and 2017 from the Economic Census (e.g., revenue, employment).
   - Compare economic outcomes using state-of-the-art econometric approaches while controlling for regional and national economic trends.
   - Evaluate whether the spatial resolution of the available data can significantly impact the study results.

Task 1 – Generate Final Results for Analyses of Aircraft Noise and Hypertension

Boston University

Objective

To generate final results of analyses of aircraft noise (day-night average sound level (DNL)) and hypertension.

Research Approach

We will intersect modeled noise exposure surfaces for 1995, 2000, 2005, 2010, and 2015 with geocoded addresses of the participants over the follow-up period. We will select a large set of *a priori* variables to be examined as confounders and/or effect modifiers and will use time-varying Cox proportional hazards models to estimate hypertension or CVD risks associated with time-varying aircraft noise exposure, while adjusting for both fixed and time-varying covariates. We will also perform a sensitivity analysis to address potential biases.

Milestones

Generate results from analyses of aircraft noise (DNL and Leq Night) and hypertension (January 2020).
Present at the University of California, Davis Aviation Noise and Emissions Symposium (March 2020).

Major Accomplishments

- Determined the person-time of people free of hypertension at baseline (1995).
- Incorporated updated NHS and NHS II data relevant to this analysis.
- In response to comments, reevaluated the process for selecting variables (potential confounders) to include in the analysis from the variables: age, alcohol use (g/day), body mass index (BMI), calendar year, comorbidities (diabetes, hearing loss, and hypercholesterolemia), smoking status, diet (dietary approaches to stop hypertension [DASH] score), hearing problems, family history of hypertension, individual-level socioeconomic status (SES) variables (educational attainment, marital status, and partner's educational attainment), medication use (current statin and non-narcotic analgesic drug use), menopausal status, physical activity (metabolic equivalent hours per week), and race, as well as region, latitude, area-level SES variables (census-tract median income and house value), and air pollution ($PM_{2.5}$ and $PM_{2.5\text{-}10}$). Initially chose potential confounders *a priori* through literature review, then ran bivariable models adjusting for each potential confounder separately examining model Akaike information criterion (AIC; a mathematical method for evaluating model fit), then built multivariable models by adding one variable in at a time and comparing AICs.
- Using updated NHS and NHS II data and final variable selection, reran time-varying Cox proportional hazards models to estimate hypertension risks associated with time-varying aircraft noise exposure, while adjusting for both fixed and time-varying covariates. Analysis performed with the DNL noise metric.

- Performed analysis for each cohort separately (Tables 1 and 2 for NHS and NHS II, respectively).
- Performed meta-analysis to combine the results found for each cohort, NHS and NHS II.
- Performed the following sensitivity analyses (assessing the sensitivity of each primary analysis to underlying issues).
  - Restricted participants to those living close to one of the 90 modeled airports (≥45 dB) to address potential exposure errors, for example, to exclude those living near an airport that is not included in the 90 airports and to minimize the impact of potential differences in populations living close to airports versus those living farther away.
  - Analyzed the potential effect of noise abatement programs for DNLs higher than 65 dB to address possible exposure errors related to noise abatement programs among those with noise exposure above the FAA threshold (>65 dB).
  - Adjusted for air pollution and area-level SES, which is available for only a portion of the time period.
- Presented on "Long-term aircraft noise exposure and the risk of hypertension in national US studies" at the University of California, Davis Aviation Noise and Emissions Symposium in San Diego, CA on March 2, 2020.

Table 1. Hazard ratios (95% confidence intervals (Cis)) for hypertension associated with aircraft noise in the NHS, comparing results for ≥55 dB with those for <55 dB

Model for DNL Beta Estimate	Ratio	LCL	UCL	p-value
Age and calendar-year adjusted	1.08	0.97	1.21	0.17
Multivariable*	1.05	0.94	1.17	0.42

*Multivariable model: Adjusted for age, calendar year, race, menopause status, family history of hypertension, and comorbidities (diabetes, hypercholesterolemia), body mass index (BMI), physical activity, alcohol use, DASH (dietary approaches to stop hypertension), medication use (current statin and NSAID use), spouse's education attainment, neighborhood level socioeconomic status (SES), and region of residence

Table 2. Hazard ratios (95% confidence intervals (Cis)) for hypertension associated with aircraft noise in the NHS II, comparing results for ≥55 dB with those for <55 dB

Model for DNL Beta Estimate	Ratio	LCL	UCL	p-value
Age and calendar-year adjusted	1.11	0.99	1.24	0.08
Multivariable*	1.08	0.97	1.21	0.17

*Multivariable model: Adjusted for age, calendar year, race, menopause status, family history of hypertension, and comorbidities (diabetes, hypercholesterolemia), BMI, physical activity, alcohol use, DASH, medication use (current statin and NSAID use), spouse's education attainment, neighborhood level SES, and region of residence

The results suggest an increased risk for incident hypertension associated with higher aircraft noise exposure in both NHS and NHS II (Tables 1 and 2). In the multivariable models of the meta-analysis across both cohorts, when compared to participants exposed to aircraft noise at levels below 55 dB, those exposed to 55 dB and above had an estimated risk of hypertension (probability of an incident of hypertension) of 1.06 times. The 95% confidence, which gives a range of estimates between which we are confident that the true value lies, was 0.98 to 1.15. The hazard ratios were relatively stable across the sensitivity analyses.

Task 2 – Generate Preliminary Results from Supporting Analyses: (a) Trends in Aircraft Noise Exposure and (b) Sociodemographic Patterning of Aircraft Noise Exposure

Boston University

Objective

To understand changes in exposure that will facilitate our interpretation of time-varying exposure measures in noise-health analyses and to understand sociodemographic patterning of noise exposure that may confound or modify potential associations of noise and health.

Research Approach
For (a, Noise Trend), we will overlay noise contours for 2000, 2005, 2010, and 2015 and census block data from the U.S. Census Bureau and American Community Surveys for 2000, 2010, and 2015 in a geographic information system to estimate population changes within noise levels. We will utilize linear fixed-effects models to estimate changes in the sizes of exposure areas based on U.S. census regions/divisions with DNL values ≥65 dB or ≥55 dB. For (b, Sociodemographic Patterning), we will describe the characteristics of populations exposed to aviation noise by race/ethnicity and income/education using the U.S. Census Bureau and American Community Survey for 2010 and will perform univariate and multivariable hierarchical analyses.

Milestone
Perform supporting analyses characterizing aircraft noise trends and sociodemographic patterns of exposure to aviation noise - N/A.

Major Accomplishments
- Overlaid noise contours for 2000, 2005, 2010, and 2015 and census block data from the U.S. Census Bureau and American Community Surveys for 2000, 2010, and 2015
- Determined the exposure area and number of people exposed to aircraft noise using data over time (2000–2015); preliminary results are presented in Figure 1.
- Determined social patterning of aircraft noise exposure by race/ethnicity and income/education for 2010 using univariate and multivariable analysis; preliminary results are presented in Figure 2 (univariable) for % black and Table 3 (multivariable; mixed effects) for airports with at least 100 census block groups.
- Investigated other statistical approaches for determining social patterning that account for multiple variables and clustering around airports and reduce potential bias. Investigated other regression methods for analyzing clustered data, such as Bayesian approaches and separating between and within cluster (airport) effects.

Exposure Area

Found non-monotonic trends in mean exposed areas for ≥55 and ≥65 dB DNL over time that peaked in 2000.
- Exposed areas largest in the Midwest region from 2000 to 2005.
- Only West region increased from 2010 to 2015.

Exposed Population

* per thousand	DNL 55 dBA			DNL 65 dBA		
	Population in 2000	Population in 2010	Δ	Population in 2000	Population in 2010	Δ
All	8352	4595	-45%	731	309	-58%
Region						
Midwest	2040	892	-56%	160	51	-68%
Northeast	2493	1381	-45%	198	86	-56%
South	2164	1359	-37%	191	68	-64%
West	1655	963	-42%	182	103	-43%

Figure 1. Preliminary results for noise trends based on exposure area (top) and number of people exposed (bottom).

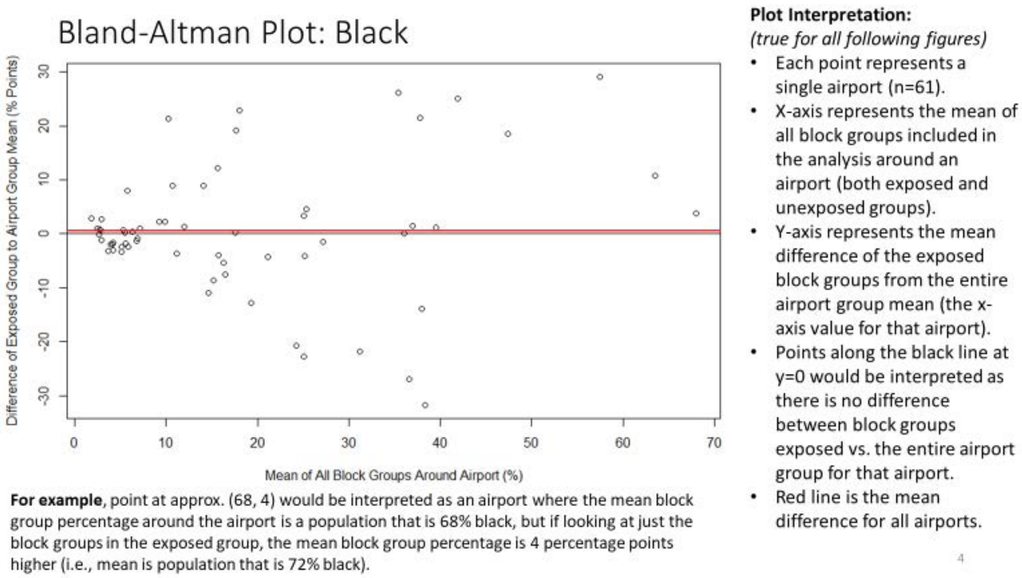

Figure 2. Preliminary results for sociodemographic patterning in aircraft noise exposure showing univariate analysis by airport of differences from mean of % black in census blocks within DNL 55 dB contours; using airport surrounded by at least 100 census blocks within the buffer zone.

Table 3. Preliminary results for sociodemographic patterning in aircraft noise exposure showing mixed-effect multivariable analysis providing odds ratio that represent percent increase (or decrease) in odds of living within DNL 55 dB noise contour per percent increase in a block group's specific population characteristic

		95% Confidence Interval	
Variable	**Odds Ratio**	**2.5%**	**97.5%**
(Intercept)	0.032	0.024	0.042
BlkGrp_PCT_Black	**0.997**	0.995	0.999
BlkGrp_PCT_Asian	**1.003**	1.000	1.007
BlkGrp_PCT_Hispanic	**1.003**	1.001	1.006
BlkGrp_PCT_Other	1.001	0.992	1.009
PCT_edu0to8	**1.013**	1.008	1.019
PCT_edu9toC	**1.015**	1.012	1.018
PCT_LT25k	**0.996**	0.992	0.999
PCT_25100k	1.002	0.998	1.005

Variables in block groups: Blk_grp_PCT_Black = percent black; Blk_grp_PCT_Asian = percent Asian; Blk_grp_PCT_Hispanic = percent Hispanic; Blk_grp_PCT_Other = percent other race; Blk_grp_PCT_white = percent white (reference); PCT_edu0to8 = percent with 0 to 8th grade education; PCT_edu9toC = percent with 9th grade to college education; PCT_C= percent college and > education (reference); PCT_LT25k = percent with income <25K; PCT_25100k = percent with income 25-100K; PCT_GT100k = percent with income >100K (reference).

Task 3 – Assess Suitability of Data on Sleep Quality and Develop a Noise-Sleep Analysis Plan

Boston University

Objective

To identify sleep measures that may be used to evaluate potential associations between noise and sleep outcomes.

Research Approach

We will review the available measures of sleep quality for the NHS to determine their timing and frequency and their relationship to the timing of the noise exposure data. We will also determine which measures, if any, are relevant to the average exposure measures. If suitable measures are found, we will develop an analysis plan to be presented to the NHS and HPFS committees.

Milestones

Assess potential analysis approaches and suitability of sleep quality data from the NHS (January 2020).
Preliminary results of analysis of annual aircraft noise and sleep quality (NHS) (September 2020).

Major Accomplishments

- Identified sleep measures in NHS and HPFS that could be used to evaluate potential association between noise and sleep outcomes.
- Developed analysis plan for noise and sleep research effort. Submitted and presented the analysis plan to NHS and HPFS oversight committees. Analysis plan was approved.
- Boston University School of Public Health Postdoc replaced Brigham and Women's Hospital Research Fellow who accepted an international faculty position.

Task 4 – Develop an Analysis Plan for Cardiovascular Disease and Aircraft Noise and Generate Descriptive Statistics

Boston University

Objective

To generate an analysis plan for studying the potential relationship between CVD and aircraft noise.

Research Approach

We will develop an analysis plan for studying CVD and aircraft noise and gain approval from the NHS and HPFS oversight committees. We will design the statistical analysis and select a large set of *a priori* variables to be examined as confounders and/or effect modifiers. We will compile appropriate data sets and run descriptive statistics.

Milestone

Generate preliminary results of analysis of aircraft noise and CVD (October 2020).

Major Accomplishments

- Developed an analysis plan for evaluating the potential relationship between CVD and noise. Submitted and presented the analysis plan to NHS and HPFS oversight committees. Analysis plan was approved.
- Determined definition of CVD to be used and inclusion and exclusion criteria.
- Determined the person-time of people free of CVD at baseline (1995).
- Determined the number of people exposed (Table 4).

Table 4. Number of CVD cases, including number of exposed cases in different exposure groups.

	NHS	NHS II
Total CVD cases	**7,818**	**1,667**
Unexposed cases	**7,284**	**1,549**
Exposed cases	**534**	**118**
At 45–54 dB(A)	*456*	*101*
At 55–64 dB(A)	*74*	*17*
At ≥65 dB(A)	*3*	*0*

Task 5 – Develop a Model for Measuring Change in Business Activities Attributable to Aircraft Noise Exposure Prototyping a Model City

Massachusetts Institute of Technology

Objective

To develop a model for measuring changes in business activities attributable to aircraft noise exposure and begin data analysis to assess potential impacts on business dynamics, controlling for confounding, prototyping one or two cities.

Research Approach

We will create a set of methods to analyze the potential economic impact of noise exposure. The methods will center on the difference-in-difference approach. In an effort to enable causal inference, this approach will focus on differences between levels of business activity before and after exogenous noise exposure changes. In addition, the approach implicitly controls for outside factors that have remained constant from start year to end year.

We will apply our approach to Boston Logan International Airport as an initial case study. This will allow us to refine choices surrounding the economic sectors selected for study and modeling choices such as the spatial resolution of gridding process.

Analyses will include, but are not limited to:

- stratification by economic sector (e.g. retail),
- stratification by geographic concentration at the community-level,
- starting with sufficiently low noise, due to perceptional effects,
- threshold-setting to detect the effects of crossing certain critical noise levels,
- identification of comparable regions (e.g., urban-to-urban, rural-to-rural).

Milestone

Briefing on airport sample, experimental setting and noise contour data for economic analysis (April 2020).

Major Accomplishments

- Completed a review of the validity and internal consistency of high-resolution business data that is used to determine changes in economic outcomes. Business data was cleaned and reorganized.
- Identified necessary noise data required for comparing between and within cities and determined the timeline for obtaining that data.
- In our preliminary case studies for Boston Logan (BOS), no significant relationship between noise exposure and business dynamics has yet been found (see Figures 3 and 4).

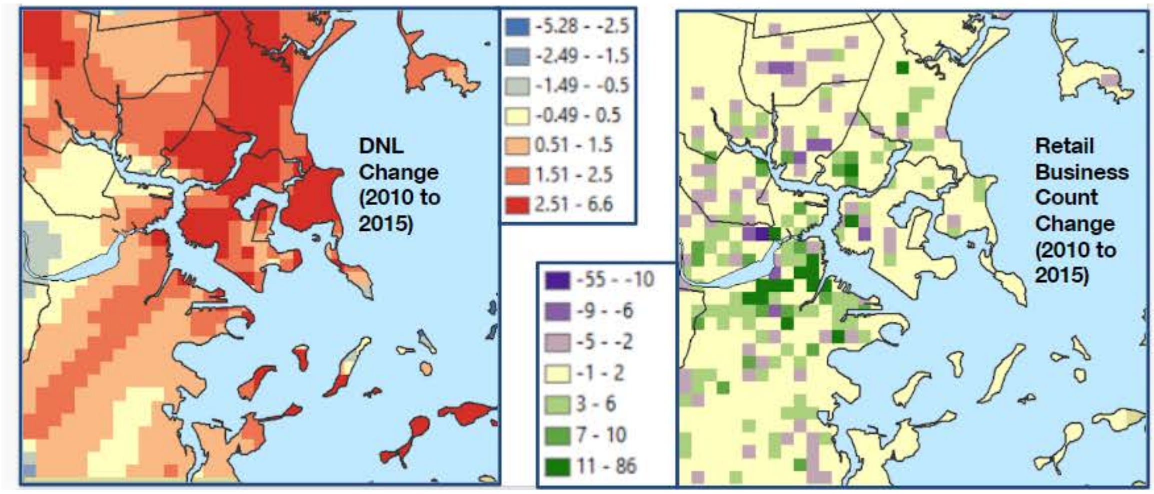

Figure 3. Change to DNL in dB from 2010 to 2015, centered on BOS, gridded at 500 m resolution (left). Change in number of retail business in each cell from 2010 to 2015 (right).

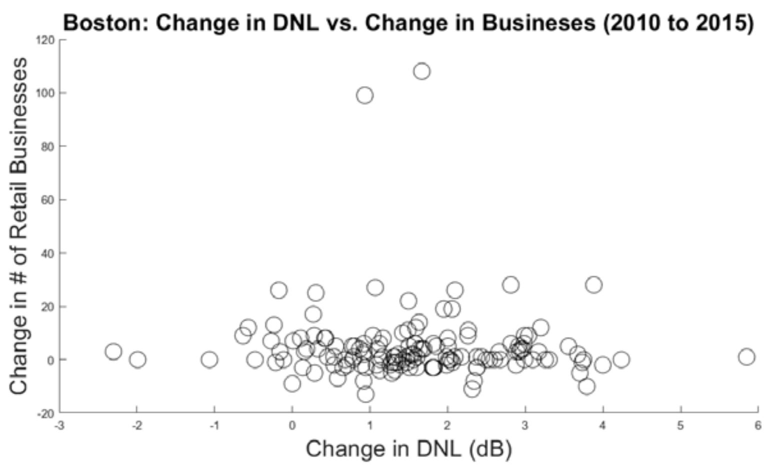

Figure 4. Scatterplot of business dynamics against noise change. Each point represents a cell in the Boston area shown in Figure 3. Cells with business decline are not overrepresented among cells with high-magnitude noise increases.

Publications
N/A

Outreach Efforts
Presented on current progress orally during the ASCENT Spring Meeting (March 31–April 1, 2020) and as a poster during the ASCENT Fall Meeting (September 29–30, 2020).

Presented on "Long-term aircraft noise exposure and the risk of hypertension in national US studies" at the University of California, Davis Aviation Noise and Emissions Symposium in San Diego on March 2, 2020.

Awards
None

Student Involvement

The dissertation of Chloe Kim (doctoral graduate, BU) includes the development and implementation of statistical analyses on the noise and hypertension risk. Chloe Kim graduated in the fall of 2019 and is currently working for the Environmental Science, Policy, and Research Institute.

The dissertation of Daniel Nguyen (doctoral candidate, BU) includes a characterization of the temporal trends in aviation noise surrounding U.S. airports.

The research rotation of Stephanie Grady (doctoral student, BU) includes the development and running of statistical analyses on noise and cardiovascular event risk.

Carson Bullock (master's student, MIT) is conducting economic impact analysis.

Plans for Next Period

(October 1, 2020 to September 30, 2021)

Related to 2018 FAA Reauthorization, Section 189, Tasks 1–3

- Assign noise exposure estimates to participants for Leq Day and Leq Night metrics.
- Complete models estimating the risk of hypertension associated with aircraft noise exposure and finalize a manuscript for publication in a peer-reviewed journal.
    - Update current draft of the manuscript.
    - Submit manuscript for Channing (Harvard/Brigham and Women's Hospital) and FAA review and to a professional journal.
- Perform analyses to estimate the risk of CVD events associated with aircraft noise exposure.
- Perform analyses to evaluate the relationship between noise and sleep.
- Develop abstracts for presentations at professional conferences and give presentation at ASCENT meetings.

Related to 2018 FAA Reauthorization, Section 189, Task 4

- Finalize methods to analyze the impacts of noise exposure on economic activity.
- Apply methods to other airports across the U.S. in order to analyze heterogeneities in potential business responses.
- Compare potential noise impacts to potential economic benefits of airport proximity, using results from the economic literature.

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