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ARTICLE

Imputation of missing values in a large job exposure matrix using hierarchical information

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Abstract

Job exposure matrices (JEMs) represent a useful and efficient approach for estimating occupational exposures. This study uses a large dataset of full-shift measurements and employs imputation strategies to develop noise exposure estimates for almost all broad level standard occupational classification (SOC) groups in the US. The JEM was constructed using 753,702 measurements from the government, private industry, and the published literature. Parametric Bayes imputation was used to take advantage of the hierarchical structure of the SOCs and the mean occupational noise exposures were estimated for all broad level SOCs, except those in major group 23-0000, for which no data were available. The estimated posterior mean for all broad SOCs was found to be 82.1 dBA with within- and between-major SOC variabilities of 22.1 and 13.8, respectively. Of the 443 broad SOCs, 85 were found to have an estimated mean exposure >85 dBA while 10 were >90 dBA. By taking advantage of the size and structure of the dataset, we were able to employ imputation techniques to estimate mean levels of noise exposure for nearly all SOCs in the US. Possible sources of errors in the estimates include misclassification of job titles due to limited data, temporal variations that were not accounted for, and variation in exposures within the same SOC. Our efforts have resulted in an almost completely populated noise JEM that provides a valuable tool for the assessment of occupational exposures to noise. Imputation techniques can lead to maximal use of available information that may be incomplete.

Keywords Personal exposures · Epidemiology · Empirical/statistical models · Exposure modeling

Background

Noise-induced hearing loss (NIHL) is the most common workplace injury, affecting an estimated 11.4% of workers in the United States [1]. While it is difficult to quantify the economic costs of NIHL, the US Veterans Administration reported direct costs of $1.2 billion in 2006 on hearing disability and tinnitus in addition to $288 million spent annually by the Veterans Administration on hearing aids [2, 3]. More recently, we have estimated the direct and indirect costs of preventable NIHL to be between $58 and $152 billion annually in the US, with a central estimate of $123 billion per year [4]. Thus, it is reasonable to assume that NIHL has a substantial and underappreciated ongoing impact on the US economy. Despite the clear relationship between hazardous noise exposure (>85 dBA) and hearing loss, it is estimated that more than 22 million US workers are exposed to hazardous levels of noise at work [5, 6].

While it is well-established that hazardous noise exposure causes NIHL, conducting occupational epidemiological studies to further elucidate and quantify this relationship is challenging. Ideally, prospective cohort studies would be implemented to follow workers and monitor their noise exposure for a decade or more until the onset of significant NIHL. However, the costs and time required to conduct a longitudinal study make this approach difficult and rare. Typically, researchers instead rely on retrospective cohort studies to assess the relationship between an occupational exposure and a disease [7]. In these retrospective studies, it can be difficult to accurately estimate exposures [8]. To overcome these difficulties, researchers have increasingly relied on job exposure matrices (JEMs) to retrospectively assess occupational exposures [7, 9–13].

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In its most basic form, a JEM consists of two axes: one axis contains a list of jobs or job descriptions, and the other contains qualitative or quantitative information about the magnitude and/or prevalence of an exposure [7]. A JEM can be further refined by adding further information on specific job tasks, and the time period of exposure. The main advantage of a JEM is that it allows the use of previously collected industrial hygiene measurement records that greatly simplify epidemiological exposure assessment. A well-constructed JEM also makes it possible to identify occupations and industries that have potentially high levels of an exposure so that additional assessment and targeted controls can be implemented to reduce potential exposures.

There are many issues that arise when using a JEM as an exposure assessment tool. The first is that exposure varies depending on both a worker's job title and the industry that the worker is employed in [14]. Workers with similar job titles can have large differences in their exposures depending on the industry they are employed in. It has also been shown that the majority of purportedly homogeneously exposed groups (HEGs) of workers—often based on job title—in the same workplace had more than a 2-fold difference in exposures [15]. The second issue is that exposures typically vary over time for a worker in the same job as changes in their workplace lead to a change in exposure patterns [7, 15]. Finally, data scarcity often necessitates the use of qualitative exposure measures, which reduce the statistical power of a JEM to detect an exposure–response relationship [16].

The JEM we describe here consists of 753,702 full-shift occupational noise measurements made according to the Occupational Safety and Health Administration's (OSHA) Permissible Exposure Limit (PEL) for noise [17]. Our previous meta-analysis of a subset of 715,867 measurements included in this JEM found that 26.4% of 235 job titles had no heterogeneity across sources (literature, government, and industry reported sources), while 63.0% of job titles were found to have moderate to high levels of heterogeneity [18]. Despite the size and scope of this dataset, many job titles still lack exposure information. The goal of this present study is to take advantage of the hierarchical structure of the job title system used in this JEM in order to develop imputation strategies to calculate estimates of exposure and variability for job titles in which no exposure information is available and then determine which job titles have an estimated exposure greater than the current OSHA action level (AL) of 85 dBA and PEL of 90 dBA.

Methodology

The JEM was constructed using OSHA [17] and Mine Safety and Health Administration (MSHA) [19] PEL measurements (i.e., a 90 dBA criterion level and threshold, and 5 dB time–intensity exchange rate) from government databases maintained by OSHA and MSHA, measurements from the published literature, and measurements submitted by private industry (Table 1). Details about the data cleaning process for the JEM have been described elsewhere [18, 20]. Briefly, data were received from the various sources in an electronic format, typically a Microsoft Excel file (Redmond, WA). The data were imported in to STATA 14 (College Station, TX) for data cleaning. Industry information was first coded using the 2012 North American Industrial Classification System (NAICS) from the US Census Bureau [21]. Using information on the industry of employment and job titles from the various government agencies, companies, and published literature from which measurement data were drawn, each measurement was assigned a job title using the Bureau of Labor Statistics' 2010 Standard Occupational Classification (SOC) [22].

The SOC structure is hierarchical and made up of major, minor, broad, and detailed groups. Figure 1 provides an example of this structure using the detailed SOC 33-9099 which corresponds to the SOC group of "Protective Service Workers, All Other" and is nested in the broad SOC 33-9090, "Miscellaneous Protective Service Workers". The broad SOC is in turn nested in the minor SOC 33-9000, "Other Protective Service Workers," which resides within the major SOC 33-0000, "Protective Service Occupations".

To take advantage of the hierarchical structure of the SOC system, we chose to use a parametric Bayes imputation method to impute missing values at the broad SOC level. Imputation is a widely used method for filling out missing values [23]. We performed a parametric imputation algorithm [24–26] (assuming that some broad SOC means are observed while other broad SOC means are missing at random, and that these observed broad SOC means and the broad SOC means to be estimated are all normally distributed defined by a set of parameters) [27]. All models were performed in R. There were a total of 461 broad SOCs, 222 (48%) of which had missing data. Of these 222 broad SOCs, four were in the major SOC group 23-0000 (Legal Occupations). Because we did not have any measurements for this occupational group, we could not perform any imputation; imputation was possible for all other broad SOCs. We first created training and validation datasets to evaluate imputation accuracy by comparing observed and imputed data in the validation dataset in order to benchmark our imputation against the truth. We then used the full dataset to impute missing values for each broad SOC to be used for future research.

Model construction and validation

As the SOC preserves a hierarchical structure such that there is a hierarchy of nested populations, it is natural to

Table 1 Source of data used in the analysis

	Before 1984	1984–1992	1993–2000	2001–2009	After 2009	Total
Total	109,123	203,071	157,471	198,987	85,050	753,702
Government	90,305	187,886	142,899	151,078	70,909	643,077
MSHA	55,318	159,701	132,302	135,753	66,065	549,139
OSHA	34,987	28,185	10,597	15,325	4844	93,938
Private Industry	18,256	15,067	13,566	46,107	11,922	104,918
Agriculture, Forestry, Fishing, and Hunting	638	44	56	15	51	804
Mining, Quarrying, and Oil and Gas Extraction	1388	6085	5695	7514	1830	22,512
Utilities	13	8	111	56	458	646
Construction	827	186	719	1113	161	3006
Manufacturing	14,995	8279	6272	36,875	8986	75,407
Wholesale Trade	16	17	4	194	129	360
Retail Trade	30	12	87	13	25	167
Transportation and Warehousing	38	152	56	51	96	393
Information	26	11	1	1	0	39
Finance and Insurance	0	0	0	0	0	0
Real Estate and Rental and Leasing	0	0	0	0	1	1
Professional Scientific and Technical Services	9	0	2	11	1	23
Management of Companies and Enterprises	0	0	0	0	0	0
Administrative and Support and Waste Management and Remediation Services	19	14	11	2	8	54
Educational Services	42	17	39	124	125	347
Health Care and Social Assistance	26	14	44	18	8	110
Arts Entertainment and Recreation	0	0	11	11	9	31
Accommodation and Food Services	6	28	34	46	2	116
Other Services (except Public Administration)	67	69	194	56	14	400
Public Administration	116	131	230	7	18	502
Published Literature	562	118	1006	1802	2219	5707

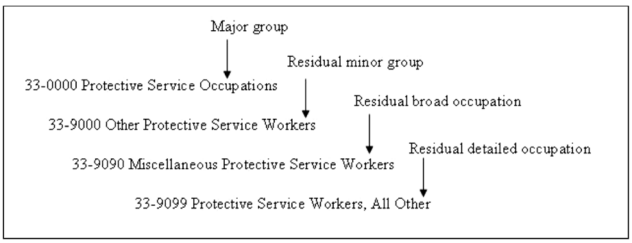

Fig. 1 Example of the hierarchical structure in the SOC system reprinted from the 2010 SOC User Guide [22]

consider using an appropriate statistical model that efficiently captures this data structure. A hierarchical model was used to estimate missing values in the dataset in our analysis [28]. The derivation of the method used is presented in Appendix 1. Let i denote the index of major SOCs and let j denote the index of broad SOCs that are nested within the major SOCs. There are two data components in this model: the observed SOCs and the missing SOCs. We assign separate indices for these two data components. For those broad SOCs that are observed, Y_{ij}^{obs} is the sample mean of the jth broad SOC in the ith major SOC. Consider a model describing our information about a hierarchical dataset $\left\{Y_1^{\text{obs}}, \ldots, Y_I^{\text{obs}}\right\}$ where $Y_i^{\text{obs}} = \left\{Y_{i1}^{\text{obs}}, \ldots, Y_{in_i}^{\text{obs}}\right\}$ consisting of all the observed data in the ith major SOC. s_{ij}^{obs} and n_{ij}^{obs} are the corresponding sample standard deviation and sample size, respectively, corresponding to the jth broad SOC nested in the ith major SOC. All that is known

about this dataset are Y_{ij}^{obs}, s_{ij}^{obs}, and n_{ij}^{obs} and the hierarchical structure of the dataset. θ_{ij}^{obs} is the true (unknown) mean of jth observed broad SOC in the ith major SOC and is described in Eq. 1 while θ_{ik}^{mis} is the true mean of kth missing broad SOC in the ith major SOC.

$$Y_{ij}^{\text{obs}} \sim N\left(\theta_{ij}^{\text{obs}}, \frac{\left(s_{ij}^{\text{obs}}\right)^2}{n_{ij}^{\text{obs}}}\right). \tag{1}$$

The random variables θ_{ij}^{obs} can be thought of as independent samples from the major SOC with index i, described by some fixed but unknown feature parameter θ_i and σ^2, where θ_i is the true mean of ith major SOC and σ^2 is the variation of broad SOCs within this major SOC. Similarly, the random variables θ_{ik}^{mis} can also be thought of as independent samples from the major SOC with index i, described by θ_i and σ^2. In the normal model, we model the data as conditionally independent and identically distributed (i.i.d.) normal (θ_i, σ^2):

$$\theta_{ij}^{\text{obs}} \sim N\left(\theta_i, \sigma^2\right),$$

$$\theta_{ik}^{\text{mis}} \sim N\left(\theta_i, \sigma^2\right).$$

To represent the information about θ_i, we treat $\theta_i, i = 1, \ldots, I$ as independent samples from the population mean. Assume the true population mean level is μ and the variation among all major SOCs is τ^2. Then the distribution of θ_i is

$$\theta_i \sim N\left(\mu, \tau^2\right).$$

In sum, we have a hierarchical normal model that describes the heterogeneity of means across different broad SOCs and major SOCs. In this hierarchical model, we assume that the within- and between-major SOC sampling models are both normal. We further assume that the sample mean of each broad SOC is distributed around the true mean of that broad SOC. The within-major SOC sampling variance σ^2 is assumed to be constant across major SOC groups and the between-major SOC sampling variance τ^2 is also assumed to be constant. The fixed but unknown parameters in this model are $\theta_{ij}^{\text{obs}}, i = 1, \ldots, I; j = 1, \ldots, n_i^{\text{obs}}$, $\theta_{ik}^{\text{mis}}, i = 1, \ldots, I; k = 1, \ldots, n_i^{\text{mis}}$, $\theta_i, i = 1, \ldots, I$ and μ, τ^2, σ^2 which will be estimated. For the parametersμ, τ^2, σ^2, we need to specify prior distributions on them. We chose to use the standard conjugate normal and inverse-gamma prior distributions for these parameters as shown in Eq. 2:

$$\begin{aligned} \tau^2 &\sim \text{Inv} - \text{gamma}\left(\frac{\eta_0}{2}, \frac{\eta_0 \tau_0^2}{2}\right); \\ \sigma^2 &\sim \text{Inv} - \text{gamma}\left(\frac{\upsilon_0}{2}, \frac{\upsilon_0 \sigma_0^2}{2}\right); \mu \sim N\left(\mu_0, \gamma_0^2\right), \end{aligned} \tag{2}$$

implying the densities $p(\tau^2) = \frac{1}{\tau^{2\left(\frac{\eta_0}{2}+1\right)}} \exp\left(-\frac{\eta_0 \tau_0^2}{2\tau^2}\right)$ and $p(\sigma^2) = \frac{1}{\sigma^{2\left(\frac{\upsilon_0}{2}+1\right)}} \exp\left(-\frac{\upsilon_0 \sigma_0^2}{2\sigma^2}\right)$.

Since no prior information is available, we specify non-informative priors for all these parameters. A graphical representation of the model is presented in Fig. 2.

The unknown quantities include the broad SOC means $\theta_{ij}^{\text{obs}}, i = 1, \ldots, I;$ $j = 1, \ldots, n_i^{\text{obs}}$, $\theta_{ik}^{\text{mis}}, i = 1, \ldots, I; k = 1, \ldots, n_i^{\text{mis}}$, the major SOC means $\theta_i, i = 1, \ldots, I$, the population mean μ, the within-major SOC sampling variance σ^2, and the between-major SOC sampling variance τ^2. Posterior inference for these parameters can be made by constructing a Gibbs sampler, which is an iterative algorithm that construct a dependent sequence of posterior samples by sweeping through each variables to sample from its conditional distribution with the remaining variables fixed at their current values [29]. After some calculation, we find that the conditional distribution of every mean parameter, including the broad SOC means $\theta_{ij}^{\text{obs}}, i = 1, \ldots, I; j = 1, \ldots, n_i^{\text{obs}}$, $\theta_{ik}^{\text{mis}}, i = 1, \ldots, I; k = 1, \ldots, n_i^{\text{mis}}$, the major SOC means $\theta_i, i = 1, \ldots, I$, the population mean μ, is normal. The

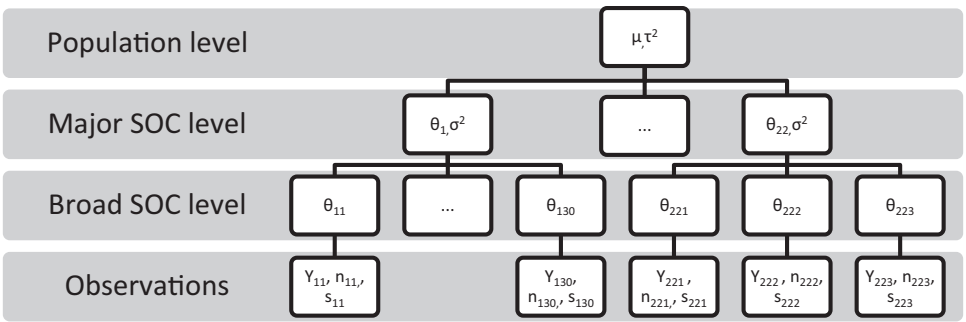

Fig. 2 An illustration of the hierarchical structure used in this analysis. There are 22 major SOCs and various number of broad SOCs within each major SOC. For example, the first major SOC has 22 broad SOCs and the 22nd major SOC has three broad SOCs. **a** Difference between predicted and observed broad SOC means in the training dataset ($n = 189$). **b** Difference between predicted and observed broad SOC means in the validation dataset ($n = 50$)

conditional distribution of SOC sampling variance σ^2 and the conditional distribution of the between-major SOC sampling variance τ^2 are both inverse gamma.

Posterior approximation proceeds by iterative sampling of each unknown quantity from its full conditional distribution. We choose the number of iterations S to be 10,000 and set the starting values for each of these parameters. Given a current state of the unknowns $\left\{\theta_{11}^{\mathrm{obs}(s)}, \ldots, \theta_{In_I}^{\mathrm{obs}(s)}, \theta_{11}^{\mathrm{mis}(s)}, \ldots, \theta_{In_I}^{\mathrm{mis}(s)}, \theta_i^{(s)}, \mu^{(s)}, \tau^{2(s)}, \sigma^{2(s)}\right\}$, a new state is generated as follows:

1. Posterior step: sample $\theta_i^{(s+1)}, i = 1, \ldots, I$ from $\theta_i | \mu^{(s)}, \theta_{i1}^{\mathrm{obs}(s)}, \ldots, \theta_{in_i}^{\mathrm{obs}(s)}, \theta_{i1}^{\mathrm{mis}(s)}, \ldots, \theta_{in_i}^{\mathrm{mis}(s)}, \tau^{2(s)}, \sigma^{2(s)}$ based on its full conditional distribution
2. Posterior step: sample $\mu^{(s+1)}$ from $\mu | \theta_1^{(s+1)}, \ldots, \theta_I^{(s+1)}, \tau^{2(s)}$
3. Posterior step: sample $\tau^{2(s+1)}$ from $\tau^2 | \theta_1^{(s+1)}, \ldots, \theta_I^{(s+1)}, \mu^{(s+1)}$
4. Posterior step: sample $\sigma^{2(s+1)}$ from $\sigma^2 | \theta_{11}^{\mathrm{obs}(s)}, \ldots, \theta_{In_I}^{\mathrm{obs}(s)}, \theta_{11}^{\mathrm{mis}(s)}, \ldots, \theta_{In_I}^{\mathrm{mis}(s)}, \theta_1^{(s+1)}, \ldots, \theta_I^{(s+1)}$
5. Posterior step: sample $\theta_{ij}^{\mathrm{obs}(s+1)}, i = 1, \ldots, I, j = 1, \ldots, n_i^{\mathrm{obs}}$ from $\theta_{ij}^{\mathrm{obs}} | \theta_i^{(s+1)}, \sigma^{2(s+1)}$
6. Imputation step: sample $\theta_{ij}^{\mathrm{mis}(s+1)}, i = 1, \ldots, I, j = 1, \ldots, n_i^{\mathrm{mis}}$ from $\theta_{ij}^{\mathrm{mis}} | \theta_i^{(s+1)}, \sigma^{2(s+1)}$.

The procedures were repeated S times until convergence has reached. After a thinning procedure and a burn-in period, the draws were used for the posterior inference. A detail description of this Bayesian parametric imputation procedure is presented in Appendix 1.

Prior to imputation of the full JEM, the imputation model was evaluated by dividing the available data in to a training and validation set. The training dataset consisted of 189 broad SOCs that were randomly chosen from the available dataset of 239 broad SOCs provided the broad SOC contained more than one measurement, as imputation cannot be conducted with one measurement. The remaining 50 broad SOCs, including those with a single measurement, were assigned to the validation dataset. The posterior distribution of the mean and variances was calculated at the broad and major SOC level in the training dataset and compared to the observed data in the validation dataset. After the model evaluation, the training and validation datasets were combined, and all data were used for imputation of the final JEM. A level of confidence was assigned for each estimate based on the width of that estimate's 95% creditable interval. Estimates with a 95% creditable interval with a width <3 dB were considered high confidence, ≤3 dB but ≤12 dB moderate confidence, and >12 dB low confidence. These values were chosen because an increase of 3 dB is roughly equivalent to doubling sound power and is also the doubling rate used by the US National Institute for Occupational Safety and Health (NIOSH), European Union, and International Organization for Standardization [6, 30, 31].

Temporal changes in exposure patterns have been shown to be important for multiple different agents [14, 20, 32]. However, the scarcity of data in certain broad level SOCs made it impractical to include a factor for the effect of time in the imputation model, in our study. Considering the possibility of temporal trend, a sub-analysis was further conducted to determine the effect of time on noise exposure levels across all the major SOCs. We chose five different year bins (before 1984, 1984–1992, 1993–2000, 2001–2009, and after 2009) which are approximately equal in length and also reflect regulatory changes promulgated by OSHA and MSHA. This analysis cannot be used to adjust the estimates from the main analysis but provides additional insight in to a possible source of error in the exposure estimates.

Results

A summary of the estimates from the model validation is presented in Table 2, where the population mean (μ) is estimated to be 82.4 dBA, the within-major SOC variance (σ^2) is 20.0, and the between-major SOC variance (τ^2) is 13.3. The estimated mean noise exposure for each major SOC ranged from 78.4 (43-0000, "Office and Administrative Support Occupations") to 85.5 dBA (45-0000, "Farming, Fishing, and Forestry Occupations"). The 95% credible interval varied depending on the number of broad SOCs present within each major SOC (Table 3). Figure 3. displays a fairly strong agreement between the 189 estimated and observed broad SOC means in the training dataset. However, Fig. 3b illustrates that the agreement between the observed and predicted SOC means in the validation dataset was not as strong as the training dataset as expected. Of the 50 broad SOCs in the validation dataset, 11 observed sample means were outside the 95% credible interval and 39 fell inside the credible interval; however,

Table 2 Summary of posterior distribution of parameters from the model validation

Parameter	Posterior mean	Posterior standard deviation	95% Credible interval
μ	82.3	0.9	80.6–84.2
σ^2	20.0	2.5	15.7–25.9
σ	4.4	0.3	3.9–5.1
τ^2	13.3	5.3	6.2–26.5
τ	3.5	0.7	2.5–5.2

Table 3 Posterior distribution of major SOC means from the model validation

Major SOC	Major SOC title	Posterior mean	Posterior standard deviation	95% credible interval	Number of broad SOCs[a]	Total number of measurements
11-0000	Management Occupations	81.8	1.8	78.4–85.3	7	277
13-0000	Business and Financial Operations Occupations	82.7	2.4	78.2–87.6	3	39
15-0000	Computer and Mathematical Occupations	80.9	2.7	75.4–86.1	2	25
17-0000	Architecture and Engineering Occupations	80.7	1.6	77.6–84.0	7	1446
19-0000	Life, Physical, and Social Science Occupations	82.8	2.0	78.9–86.8	4	183
21-0000	Community and Social Service Occupations	80.7	2.8	74.7–86.0	2	7
25-0000	Education, Training, and Library Occupations	84.0	2.9	78.5–89.6	2	33
27-0000	Arts, Design, Entertainment, Sports, and Media Occupations	82.1	2.00	78.2–86.1	5	77
29-0000	Healthcare Practitioners and Technical Occupations	79.9	1.8	76.2–83.3	6	89
31-0000	Healthcare Support Occupations	82.3	2.9	76.6–87.9	1	15
33-0000	Protective Service Occupations	81.2	1.8	77.6–84.7	5	106
35-0000	Food Preparation and Serving Related Occupations	82.7	1.7	79.7–85.9	8	107
37-0000	Building and Grounds Cleaning and Maintenance	85.0	2.5	80.2–89.8	2	353
39-0000	Personal Care and Service Occupations	84.8	1.9	80.9–88.6	5	47
41-0000	Sales and Related Occupations	82.3	2.1	78.2–86.6	3	191
43-0000	Office and Administrative Support Occupations	78.4	1.2	76.2–80.6	16	433
45-0000	Farming, Fishing, and Forestry Occupations	85.5	2.0	81.7–89.5	4	305
47-0000	Construction and Extraction Occupations	83.5	0.9	81.8–85.1	27	93,531
49-0000	Installation, Maintenance, and Repair Occupations	83.3	1.2	80.9–85.5	14	8923
51-0000	Production Occupations	85.2	0.7	83.9–86.6	43	26,989
53-0000	Transportation and Material Moving Occupations	83.3	0.9	81.5–85.2	21	16,456
55-0000	Military Specific Occupations	78.9	2.8	73.2–83.9	2	12

[a]Number of broad SOCs in the training dataset

seven of these broad SOCs that fell outside contained only one measurement (Fig. 4).

Table 4 summarizes the population mean, and the within- and between-major SOC variance for the entire dataset (i.e., the combined validation and training datasets). The population mean was estimated to be 82.1 dBA and the within- and between-major SOC variance was estimated to be 22.1 and 13.8, respectively. The estimated mean noise exposure for each major SOC ranged from 78.6 (25-0000, "Education, Training, and Library Occupations") to 86.4 dBA (45-0000, "Farming, Fishing, and Forestry Occupations"). Similar to what we observed in the model validation results (Table 3), major SOCs that consisted of a larger number of broad SOCs had smaller 95% credible intervals (Table 5).

The model predictions at the broad SOC level can be found in Table 6 and Figs. 6 and 7 or online at http://noisejem.sph.umich.edu/full_results.pdf. The estimated population mean was 82.1 dBA while the estimated population standard deviation was 3.1 dBA. Of the 443 broad SOCs, 338 (76.3%) were found to have an estimated mean exposure >80 dBA, while 85 (19.2%) were found to have an estimated mean exposure greater than the current OSHA AL of 85 dBA. Additionally, 10 broad SOCs were found to have an estimated mean exposure greater that the OSHA PEL of 90 dBA. The distribution of estimated broad SOC means can be found in Fig. 5, which indicates that the majority of broad SOCs have estimated mean noise exposure levels between 80 and 85 dBA. A total of 99 (22.3%) and 108 (24.3%) of the

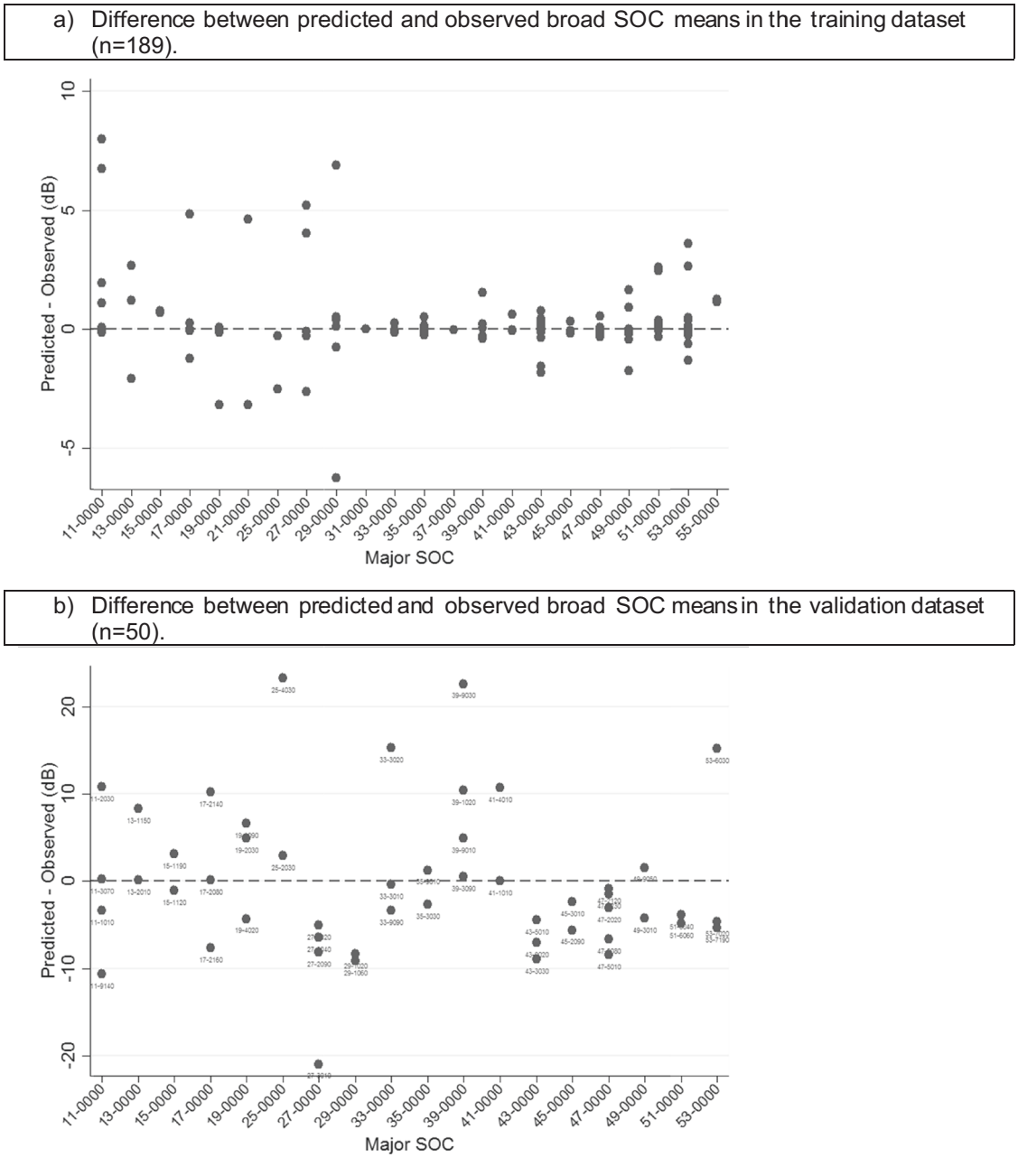

Fig. 3 Comparison of predicted and observed broad SOC means for the training (**a**) and validation (**b**) datasets

broad SOCs were found to have a high and moderate level of confidence in the estimate, respectively.

An additional sub-analysis was conducted, attempting to determine the effect of time on exposure estimates. The results of this additional analysis found that nine (40.9%) of the major SOCs (11-0000, 25-0000, 37-0000, 41-0000, 43-0000, 47-0000, 49-0000, 51-0000, and 53-0000) had decreasing exposures over time. This suggests that for some broad and major SOCs, temporal trends may impact exposures estimates. While these results provide additional insight in regard to the impact of time on the original exposure estimate, these new results have less practical use because the major SOCs do not provide sufficient job title specificity to accurately assign exposure estimates. The full results of this additional analysis can be found in Table 7.

Discussion

In this study, we used principled validation strategy to evaluate the performance of an imputation strategy to

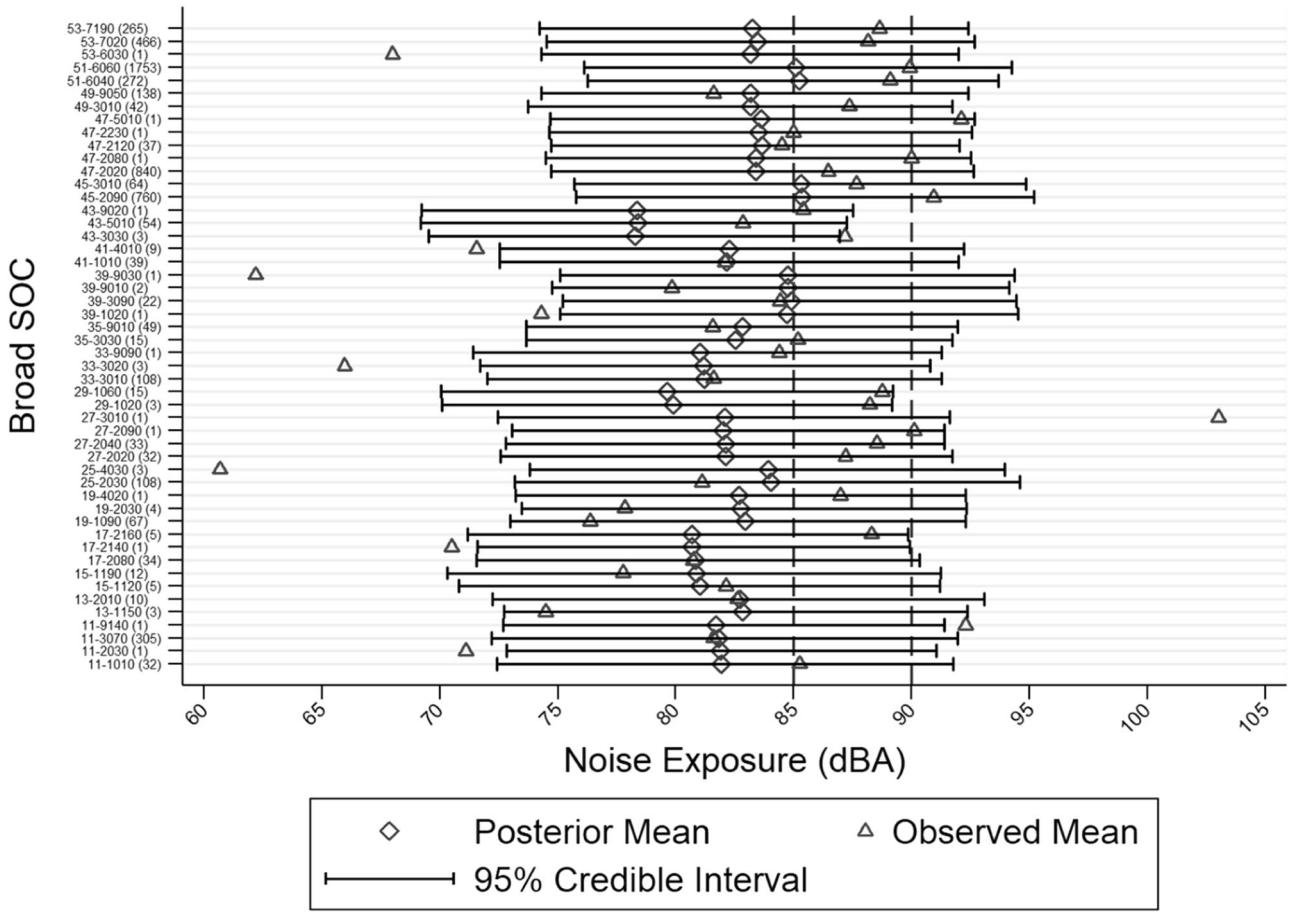

Fig. 4 Posterior and observed broad SOCs means for the validation dataset ($n = 50$). The sample size for the observed mean is shown in parentheses

Table 4 Summary of posterior distribution of parameters from the model imputation

Parameter	Posterior mean	Posterior standard deviation	95% Credible interval
μ	82.1	0.9	80.3–83.9
σ^2	22.1	2.5	17.7–27.5
σ	4.7	0.3	4.2–5.3
τ^2	13.8	5.1	6.6–26.6
τ	3.7	0.7	2.6–5.2

estimate noise exposures in a large JEM. The imputation strategy borrows information across broad SOCs by assuming a common hierarchical distribution with parameters that are shared. The imputed SOC means were assessed for imputation accuracy in a validation dataset consisting of randomly chosen subset of SOCs. The strong agreement between the 189 estimated and observed broad SOC means in the training dataset occurred because these observed broad SOCs were used to build the hierarchical model and thus their data were "known" to the model, which yielded statistically overly optimistic estimates. The broad SOCs in the validation dataset were not used in building the hierarchical model and were thus "unknown". The estimated SOC mean of a broad SOC in the training set was a weighted average of the observed SOC mean Y_{ij}^{obs} and the estimate of major SOC mean θ_i that it was nested in, and the weights were proportional to the estimated σ^2 (variation within major SOC) and $\frac{\left(s_{ij}^{\text{obs}}\right)^2}{n_{ij}^{\text{obs}}}$ (variation in the observed SOC mean). As the variation within major SOCs was high and the variation in the observed broad SOC means were small for most broad SOCs, the estimated broad SOC mean would be more similar to the observed broad SOC mean than the major SOC mean, if that broad SOC mean had been observed. However, the estimated mean of a broad SOC in the validation set was entirely based on the estimated mean of the major SOC that it was nested in; no additional information was available that could be used for this purpose. As a result, the agreement between the observed and predicted SOC means in the validation dataset was not as strongly associated as the training dataset.

Table 5 Posterior distribution of major SOC means from the model imputation

Major SOC	Major SOC title	Posterior mean	Posterior standard deviation	95% Credible interval	Number of broad SOCs[a]	Total number of measurements
11-0000	Management Occupations	82.0	1.6	78.6–85.1	9	1380
13-0000	Business and Financial Operations Occupations	81.4	2.0	77.3–85.1	5	39
15-0000	Computer and Mathematical Occupations	80.4	2.3	75.9–84.8	4	25
17-0000	Architecture and Engineering Occupations	81.3	1.5	78.3–84.4	9	7176
19-0000	Life, Physical, and Social Science Occupations	81.4	1.9	77.7–85.1	6	776
21-0000	Community and Social Service Occupations	80.6	3.0	74.7–86.3	2	7
25-0000	Education, Training, and Library Occupations	78.6	2.2	74.1–82.9	4	139
27-0000	Arts, Design, Entertainment, Sports, and Media Occupations	83.5	1.9	79.9–87.1	7	264
29-0000	Healthcare Practitioners and Technical Occupations	81.5	1.7	78.2–84.9	8	220
31-0000	Healthcare Support Occupations	82.1	2.9	76.4–87.9	1	67
33-0000	Protective Service Occupations	79.7	1.6	76.5–82.9	7	480
35-0000	Food Preparation and Serving Related Occupations	82.8	1.42	79.9–85.6	10	319
37-0000	Building and Grounds Cleaning and Maintenance	84.6	2.6	79.7–89.8	2	1675
39-0000	Personal Care and Service Occupations	84.6	1.8	81.0–88.2	7	178
41-0000	Sales and Related Occupations	81.1	1.9	77.4–84.8	5	935
43-0000	Office and Administrative Support Occupations	78.8	1.1	76.6–80.9	18	2038
45-0000	Farming, Fishing, and Forestry Occupations	86.4	1.8	83.0–89.8	6	1384
47-0000	Construction and Extraction Occupations	83.6	0.9	81.9–85.3	29	469,231
49-0000	Installation, Maintenance, and Repair Occupations	83.3	1.2	81.2–85.7	16	44,769
51-0000	Production Occupations	85.4	0.7	84.0–86.8	45	135,533
53-0000	Transportation and Material Moving Occupations	83.7	1.0	81.8–85.7	23	81,951
55-0000	Military Specific Occupations	78.8	2.8	73.1–84.1	2	12

[a]Total number of broad SOCs in the training and validation datasets

Our estimates were developed from large datasets of measurements provided by the government, private industry, and the published literature. By taking advantage of the hierarchical structure of the SOC system, we were able to use imputation to iteratively impute the missing values of the mean of the broad SOCs and to draw updated samples of the parameters based on both the means of the observed broad SOCs and the means of the missing broad SOCs. Due to the limited sample size within each minor SOC, we chose to ignore the minor SOC level in this hierarchical model. Instead we assumed that the broad SOCs within the same major SOC are more alike those broad SOCs in other major SOCs. However, if more data are available in the future and there are at least moderate numbers of broad SOC with observed measurements for most minor SOCs, it is possible to construct a hierarchical model with major SOC level, minor SOC level, and broad SOC level. Such a hierarchical model incorporating the minor SOC level may be able to provide more accurate estimates of the broad SOC means. The validation analysis on the 50 randomly chosen SOCs provide a realistic sense of accuracy when a new missing exposure is predicted for an SOC. The level of confidence assigned to each estimate indicated that 236 (53.3%) of the broad SOCs had a 95% creditable interval wider than 12 dBA, which suggests that caution should be exercised when using these exposure estimates until additional data can be collected, or the current estimates can be validated.

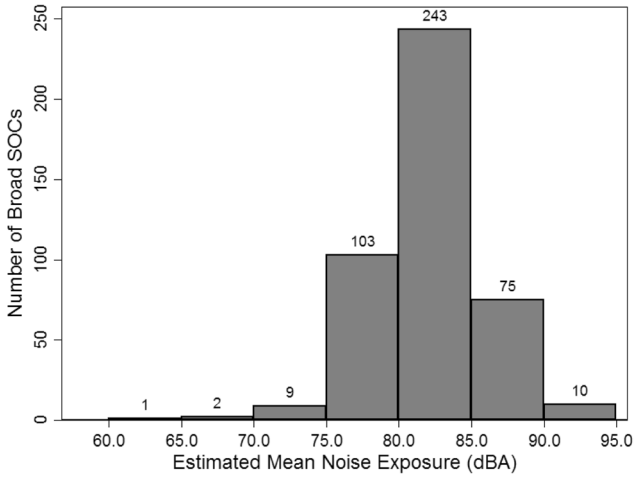

Fig. 5 The distribution of estimated mean noise exposures (dBA) at the broad SOC level. The numbers above the bars indicate the number of SOCs with estimated mean exposures that lie within that bar

In the parametric Bayes imputation method that we used, we plugged in the posterior mean estimates of the unknown quantities as our single imputation results. However, instead we could possibly create random draws from the posterior distributions of these quantities and then create multiple imputed datasets. The advantage of multiple imputation over the single imputation is that it takes into account the uncertainty in the imputation procedure.

Another potential source of error in our exposure estimates occurs because these data represent occupational noise exposures from 1970–2014. As reported by Middendorf in 2004 and Roberts et al. in 2016, occupational noise exposures have been decreasing overall in the general industry and mining sectors [14, 20]. However, the results of the few other longitudinal analyses of occupational noise exposures suggest that workers in the construction and manufacturing industries may not have experienced significant reductions over time [32, 33]. If a majority of measurements for a particular occupation were clustered in a short time span, then it is possible that the measurements used by the model to develop exposure estimates may be biased.

The largest potential source of error in our estimates is likely the variability of exposure within each broad SOC. This is a common issue for any JEM that attempts to quantify exposures across several different industries. As identified by Rappaport et al., there is considerable variation in personal exposure for workers with similar job titles within the same workplace [15]. Grouping workers by job title is a common practice in industrial hygiene because it is easy and straightforward to assign workers to an occupational group. However, as Anderson et al. have demonstrated, the standard occupational coding systems used in Canada were inadequate to accurately group workers in the pulp and paper industry [34].

We recognize that these shortcomings of the SOC system may result in misclassification of exposure. This misclassification can be exasperated by the model when limited data are available for a broad SOC within a major SOC where other broad SOCs with dissimilar exposures influence the major SOC mean. For example, the model estimated that the broad SOC 11-1010 (Chief Executives) had a mean exposure of 84.8 dBA, which runs counter to most professional intuitions. However, this high exposure value is due in part to the fact that the major SOC 11-0000 (Management Occupations) contains broad SOCs for jobs such as “Industrial Production Managers” and “Farmers, Ranchers, and other Agricultural Managers” who would be expected to have higher exposures and thus influence the exposure estimate for the “Chief Executive” broad SOC. This is due, in part, to the fact that the SOC system was designed to track economic indicators and was not intended as a classification scheme for forming similar exposure groups. However, it is still advantageous to use this system, as there are numerous crosswalks available to convert SOC codes to other occupational classifications systems so that the exposure estimates can be more easily used in epidemiological studies.

However, the variability of a broad SOC mean would be expected to decrease as the number of measurements increase because it would be expected that as more measurements are added to a broad SOC, the estimated mean would become closer to the true mean of the broad SOC. Exposure estimates could be further enhanced by using more informative priors based on expert knowledge and information from the published literature. However, we chose to make the imputation process more robust and less sensitive to subjective choices at the cost of making the process less efficient. Future efforts will be focused on incorporating expert judgment to enhance the accuracy of the JEM’s estimates, particularly for broad SOCs that we had low levels of confidence in the estimates.

The results of our analysis indicated that the majority of broad SOCs were estimated to be exposed to noise ≥80.0 and <85.0 dBA. While these broad SOCs are not estimated to exceed the OSHA AL, it is worth noting that the average estimated exposure and standard deviation for broad SOCs in this group were 82.3 and 3.6 dBA, respectively, with a 95% confidence interval between 72.3 and 89.4 dBA. This suggests that while the estimated mean exposure for these groups was below the AL, there is considerable variability in these exposures that must be considered when using these estimates to identify occupations that should be enrolled in hearing conservation programs (HCPs). In other words, individual exposures or minor SOCs within the broad SOC groups in the ≥80.0 and <85.0 dBA bin may still exceed the AL. This is in contrast to broad SOCs that are in the ≥85.0, <90.0, and >90.0 dBA groups, which have

an average estimated exposure of 87.1 and 91.6 dBA and standard deviations of 1.2 and 0.8 dBA, respectively. For these two groups, there is far greater confidence that noise exposures exceed the AL or PEL and that location-specific measurements should be taken to determine if controls should be implemented to protect workers from excessive exposure.

Exposure estimates for individual broad SOCs can be found in Table 6 and Figs. 6 and 7. While these estimates cannot replace personal measurement data, they do provide a starting point for occupational health professionals to identify workers who may be overexposed to noise. Additionally, the provided measure of variability will help inform and guide the decisions of occupational health professionals regarding workers in job groups whose exposure may vary from day to day depending on the specific work tasks being conducted. Note that these exposure estimates are calculated based on the currently available data in the JEM. If new measurements are added to the JEM in the future, these exposure estimates can be refined and updated.

To our knowledge, the exposure estimates from our model are based on the most comprehensive dataset of occupational noise exposure ever collected. The only other instance of a comprehensive JEM developed for occupational noise was reported by Sjöström et al. in 2013. The authors of that paper used a mixture of 569 quantitative noise measurements and qualitative measurements made by expert judgment to assign exposure groupings for 129 unique job families [13]. In contrast to what has been seen in the US, occupational noise exposures in Sweden saw only a slight decrease from 1970 to 2004, which likely reflects the difference in the dates of promulgation and enforcement of occupational health laws in the US compared to Sweden [13, 14]. It is not straightforward to directly compare the results from our JEM to the JEM constructed by Sjöström et al. because we only used quantitative measurements in our JEM. In addition, Sweden uses a more protective noise exposure standard than OSHA (85 dBA criterion level and 3 dB time-intensity exchange rate) while OSHA uses the less protective 90 dBA criterion level and 5 dB time–intensity exchange rate, making it impossible to directly compare the measurements [35].

Despite the limitations associated with this JEM, we believe it represents a useful tool for occupational health professionals and researchers. Our future plans include combining the exposure estimates from this model with information on the frequency of noise exposure from Department of Labor's Occupational Information Network (O*NET) system by using responses from survey question 4.C.2.b.1.a, which asks respondents to provide a response from 0–100% "How often does this job require working exposed to sounds and noise levels that are distracting or uncomfortable?" [36]. This will build on previous work by Choi et al. that used the responses from O*NET's databases to create statistical models to predict NIHL [37]. Our exposure estimates can also be used with NIHL models published by the International Organization for Standards (ISO) to predict the hearing threshold levels of participants in the National Health and Nutrition Examination Survey (NHANES), which contains both audiometric and employment history data [38, 39]. Finally, the estimates in our JEM may be used to drive additional targeted surveillance and assessment efforts in specific occupations; these efforts could leverage smart device-based measurement technologies, which under certain circumstances can yield low-cost, reasonably accurate noise exposure measurements [40, 41]. Each of these steps will yield better noise exposures estimates that can, in turn, be used to guide efforts to control noise exposures and reduce occupational NIHL.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix 1

The imputation procedure

The unknown quantities in our system include the broad SOC means θ_{ij}^{obs}, $i = 1, \ldots, I; j = 1, \ldots, n_i^{\text{obs}}$, θ_{ik}^{mis}, $i = 1, \ldots, I; k = 1, \ldots, n_i^{\text{mis}}$, the major SOC means θ_i, $i = 1, \ldots, I$, the population mean μ, the within major SOC sampling variance σ^2, and the between major SOC sampling variance τ^2. Joint posterior inference for these parameters can be made by constructing a Gibbs sampler which approximates the posterior distribution $p\left(\theta_{11}^{\text{obs}}, \ldots, \theta_{In_I}^{\text{obs}}, \theta_{11}^{\text{mis}}, \ldots, \theta_{In_I}^{\text{mis}}, \theta_1, \ldots, \theta_I, \mu, \tau^2, \sigma^2 | \text{observed data}\right)$:

$$
\begin{aligned}
& p\left(\theta_{11}^{\text{obs}}, \ldots, \theta_{In_I}^{\text{obs}}, \theta_{11}^{\text{mis}}, \ldots, \theta_{In_I}^{\text{mis}}, \theta_1, \ldots, \right. \\
& \qquad \left. \theta_I, \mu, \tau^2, \sigma^2 | \text{observed data}\right) \\
& \propto p\left(\text{observed data} | \theta_{11}^{\text{obs}}, \ldots, \theta_{In_I}^{\text{obs}}, \theta_{11}^{\text{mis}}, \ldots, \right. \\
& \qquad \left. \theta_{In_I}^{\text{mis}}, \theta_1, \ldots, \theta_I, \mu, \tau^2, \sigma^2\right) \\
& \cdot \left\{ \prod_{i=1}^{I} \prod_{j=1}^{n_i^{\text{obs}}} p(\theta_{ij}^{\text{obs}} | \theta_i, \sigma^2) \right\} \cdot \left\{ \prod_{i=1}^{I} \prod_{k=1}^{n_i^{\text{mis}}} p(\theta_{ik}^{\text{obs}} | \theta_i, \sigma^2) \right\} \\
& \cdot \left\{ \prod_{i=1}^{I} p(\theta_i | \mu, \tau^2) \right\} \cdot \pi(\mu) \cdot \pi(\tau^2) \cdot \pi(\sigma^2)
\end{aligned}
$$

Table 6 Predicted noise exposure based on model results

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
11-0000	management occupations	11-1010	chief executives	84.8	1.57	81.78	87.94	Moderate
11-0000	management occupations	11-1020	general and operations managers	81.8	4.92	72.32	91.67	Low
11-0000	management occupations	11-1030	legislators	82.0	4.87	72.46	91.57	Low
11-0000	management occupations	11-2010	advertising and promotions managers	82.0	4.85	72.42	91.52	Low
11-0000	management occupations	11-2020	marketing and sales managers	82.1	4.9	72.28	91.33	Low
11-0000	management occupations	11-3010	administrative services managers	82.1	4.95	72.25	92.18	Low
11-0000	management occupations	11-3020	computer and information systems managers	77.0	3.73	69.56	84.33	Low
11-0000	management occupations	11-3030	financial managers	82.0	5	72.21	91.76	Low
11-0000	management occupations	11-3050	industrial production managers	86.3	0.3	85.73	86.89	High
11-0000	management occupations	11-3060	purchasing managers	81.9	4.99	72.31	91.47	Low
11-0000	management occupations	11-3070	transportation, storage, and distribution managers	81.6	0.44	80.72	82.46	High
11-0000	management occupations	11-3110	compensation and benefits managers	82.0	5.07	71.67	92.22	Low
11-0000	management occupations	11-3120	human resources managers	81.9	4.83	72.46	91.31	Low
11-0000	management occupations	11-3130	training and development managers	82.0	4.89	72.61	91	Low
11-0000	management occupations	11-9010	farmers, ranchers, and other agricultural managers	92.4	0.47	91.49	93.31	High
11-0000	management occupations	11-9020	construction managers	81.9	4.98	72.41	91.68	Low
11-0000	management occupations	11-9030	education administrators	81.9	3.43	75.15	88.7	Low
11-0000	management occupations	11-9040	architectural and engineering managers	81.8	4.97	72.5	92.02	Low
11-0000	management occupations	11-9050	food service managers	81.9	5	72.51	92.17	Low
11-0000	management occupations	11-9060	funeral service managers	81.9	4.97	71.83	91.21	Low
11-0000	management occupations	11-9070	gaming managers	77.0	2	72.97	80.86	Moderate
11-0000	management occupations	11-9080	lodging managers	81.8	5.04	71.62	91.66	Low
11-0000	management occupations	11-9110	medical and health services managers	78.7	2.86	73.28	84.36	Moderate
11-0000	management occupations	11-9120	natural sciences managers	77.3	3.72	70.08	84.37	Low
11-0000	management occupations	11-9130	postmasters and mail superintendents	82.1	5.02	72.03	91.64	Low
11-0000	management occupations	11-9150	social and community service managers	81.8	4.98	72.02	91.26	Low
11-0000	management occupations	11-9160	emergency management directors	82.0	5.1	71.99	91.82	Low
11-0000	management occupations	11-9190	miscellaneous managers	82.0	4.96	71.97	91.6	Low
13-0000	business and financial operations occupations	13-1010	agents and business managers of artists, performers, and athletes	81.5	5.14	71.29	91.24	Low
13-0000	business and financial operations occupations	13-1020	buyers and purchasing agents	77.6	2.1	73.43	81.83	Moderate
13-0000	business and financial operations occupations	13-1030	claims adjusters, appraisers, examiners, and investigators	81.2	5.14	71.22	91.29	Low
13-0000	business and financial operations occupations	13-1040	compliance officers	92.8	1.89	89.22	96.55	Moderate
13-0000	business and financial operations occupations	13-1050	cost estimators	81.5	5.03	71.31	91.37	Low
13-0000	business and financial operations occupations	13-1070	human resources workers	77.9	2.94	72.1	83.48	Moderate
13-0000	business and financial operations occupations	13-1080	logisticians	81.4	5.08	71.5	91.35	Low
13-0000	business and financial operations occupations	13-1110	management analysts	81.4	5.1	71.17	91.23	Low
13-0000	business and financial operations occupations	13-1120	meeting, convention, and event planners	81.6	5.11	71.19	91.37	Low

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
13-0000	business and financial operations occupations	13-1130	fundraisers	81.5	5.14	71.16	91.23	Low
13-0000	business and financial operations occupations	13-1140	compensation, benefits, and job analysis specialists	81.4	5.15	71.05	91.68	Low
13-0000	business and financial operations occupations	13-1150	training and development specialists	74.6	0.61	73.43	75.8	High
13-0000	business and financial operations occupations	13-1160	market research analysts and marketing specialists	81.5	5.27	70.84	91.47	Low
13-0000	business and financial operations occupations	13-1190	miscellaneous business operations specialists	81.3	5.03	71.28	90.96	Low
13-0000	business and financial operations occupations	13-2010	accountants and auditors	82.2	3.09	76.36	88.55	Low
13-0000	business and financial operations occupations	13-2020	appraisers and assessors of real estate	81.4	5.19	70.83	91.44	Low
13-0000	business and financial operations occupations	13-2030	budget analysts	81.5	5.18	71.8	91.88	Low
13-0000	business and financial operations occupations	13-2040	credit analysts	81.4	5.07	71.47	90.78	Low
13-0000	business and financial operations occupations	13-2050	financial analysts and advisors	81.4	5.16	71.56	91.84	Low
13-0000	business and financial operations occupations	13-2060	financial examiners	81.3	5.21	71.24	91.52	Low
13-0000	business and financial operations occupations	13-2070	credit counselors and loan officers	81.2	4.88	71.87	90.88	Low
13-0000	business and financial operations occupations	13-2080	tax examiners, collectors and preparers, and revenue agents	81.4	5.07	71.95	91.37	Low
13-0000	business and financial operations occupations	13-2090	miscellaneous financial specialists	81.4	5.22	70.91	91.95	Low
15-0000	computer and mathematical occupations	15-1110	computer and information research scientists	80.2	5.17	69.89	90.25	Low
15-0000	computer and mathematical occupations	15-1120	computer and information analysts	81.5	3.08	75.56	87.57	Low
15-0000	computer and mathematical occupations	15-1130	software developers and programmers	79.2	2.62	73.93	84.39	Moderate
15-0000	computer and mathematical occupations	15-1140	database and systems administrators and network architects	80.3	5.29	70.13	91.31	Low
15-0000	computer and mathematical occupations	15-1150	computer support specialists	80.5	5.19	70.08	90.37	Low
15-0000	computer and mathematical occupations	15-1190	miscellaneous computer occupations	78.2	1.98	74.34	82.04	Moderate
15-0000	computer and mathematical occupations	15-2010	actuaries	80.5	5.27	70.38	90.54	Low
15-0000	computer and mathematical occupations	15-2020	mathematicians	80.4	5.2	69.95	90.71	Low
15-0000	computer and mathematical occupations	15-2030	operations research analysts	79.6	3.17	73.41	85.65	Low
15-0000	computer and mathematical occupations	15-2040	statisticians	80.3	5.34	69.89	90.62	Low
15-0000	computer and mathematical occupations	15-2090	miscellaneous mathematical science occupations	80.5	5.19	70.73	90.92	Low
17-0000	architecture and engineering occupations	17-1010	architects, except naval	81.0	4.93	71.66	90.95	Low

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
17-0000	architecture and engineering occupations	17-1020	surveyors, cartographers, and photogrammetrists	77.4	1.26	75.05	79.86	Moderate
17-0000	architecture and engineering occupations	17-2010	aerospace engineers	76.7	3.57	70.01	83.57	Low
17-0000	architecture and engineering occupations	17-2020	agricultural engineers	85.1	0.5	84.15	86.08	High
17-0000	architecture and engineering occupations	17-2030	biomedical engineers	81.3	4.93	72	91.39	Low
17-0000	architecture and engineering occupations	17-2040	chemical engineers	81.3	4.99	71.58	90.91	Low
17-0000	architecture and engineering occupations	17-2050	civil engineers	81.4	4.92	71.95	91.17	Low
17-0000	architecture and engineering occupations	17-2060	computer hardware engineers	81.1	5.06	71.39	91.13	Low
17-0000	architecture and engineering occupations	17-2070	electrical and electronics engineers	81.1	4.91	71.47	90.78	Low
17-0000	architecture and engineering occupations	17-2080	environmental engineers	80.8	1.3	78.25	83.3	Moderate
17-0000	architecture and engineering occupations	17-2110	industrial engineers, including health and safety	81.1	1.41	78.21	83.91	Moderate
17-0000	architecture and engineering occupations	17-2120	marine engineers and naval architects	81.3	4.97	71.55	91.24	Low
17-0000	architecture and engineering occupations	17-2130	materials engineers	81.1	4.85	71.67	90.78	Low
17-0000	architecture and engineering occupations	17-2150	mining and geological engineers, including mining safety engineers	80.1	0.44	79.29	81	High
17-0000	architecture and engineering occupations	17-2160	nuclear engineers	85.9	2.8	80.43	91.34	Moderate
17-0000	architecture and engineering occupations	17-2170	petroleum engineers	81.2	5.01	71.39	90.65	Low
17-0000	architecture and engineering occupations	17-2190	miscellaneous engineers	81.2	5.06	71.32	91.29	Low
17-0000	architecture and engineering occupations	17-3010	drafters	81.3	4.86	71.58	90.36	Low
17-0000	architecture and engineering occupations	17-3020	engineering technicians, except drafters	79.9	0.09	79.72	80.1	High
17-0000	architecture and engineering occupations	17-3030	surveying and mapping technicians	82.5	2.99	76.61	88.22	Moderate
19-0000	life, physical, and social science occupations	19-1010	agricultural and food scientists	81.4	5.14	71.39	91.55	Low
19-0000	life, physical, and social science occupations	19-1020	biological scientists	81.5	4.96	72.06	91.41	Low
19-0000	life, physical, and social science occupations	19-1030	conservation scientists and foresters	88.5	2.74	83.18	93.97	Moderate
19-0000	life, physical, and social science occupations	19-1040	medical scientists	81.5	5.05	71.08	91.24	Low
19-0000	life, physical, and social science occupations	19-1090	miscellaneous life scientists	76.5	0.72	75.07	77.88	High
19-0000	life, physical, and social science occupations	19-2010	astronomers and physicists	81.4	5.16	71.41	91.29	Low
19-0000	life, physical, and social science occupations	19-2020	atmospheric and space scientists	81.4	5.04	71.29	91.77	Low

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
19-0000	life, physical, and social science occupations	19-2030	chemists and materials scientists	79.6	3.47	72.95	86.5	Low
19-0000	life, physical, and social science occupations	19-2040	environmental scientists and geoscientists	81.5	5.06	71.73	91.31	Low
19-0000	life, physical, and social science occupations	19-2090	miscellaneous physical scientists	81.3	5.05	71.48	91.05	Low
19-0000	life, physical, and social science occupations	19-3010	economists	81.5	5.04	71.22	91.4	Low
19-0000	life, physical, and social science occupations	19-3020	survey researchers	81.4	4.99	71.8	91.39	Low
19-0000	life, physical, and social science occupations	19-3030	psychologists	81.4	5.17	71.52	91.75	Low
19-0000	life, physical, and social science occupations	19-3040	sociologists	81.6	5.15	71.64	91.39	Low
19-0000	life, physical, and social science occupations	19-3050	urban and regional planners	81.5	5.17	71.31	91.3	Low
19-0000	life, physical, and social science occupations	19-3090	miscellaneous social scientists and related workers	81.4	4.97	71.7	91.26	Low
19-0000	life, physical, and social science occupations	19-4010	agricultural and food science technicians	84.0	1.57	80.77	86.97	Moderate
19-0000	life, physical, and social science occupations	19-4030	chemical technicians	79.6	0.32	78.98	80.23	High
19-0000	life, physical, and social science occupations	19-4040	geological and petroleum technicians	81.5	5.05	71.45	91.65	Low
19-0000	life, physical, and social science occupations	19-4050	nuclear technicians	81.4	5.09	71.38	91.31	Low
19-0000	life, physical, and social science occupations	19-4060	social science research assistants	81.4	5.13	71.33	91.2	Low
19-0000	life, physical, and social science occupations	19-4090	miscellaneous life, physical, and social science technicians	79.4	0.7	78.01	80.72	High
21-0000	community and social service occupations	21-1010	counselors	75.4	3.49	68.55	82.23	Low
21-0000	community and social service occupations	21-1020	social workers	80.6	5.58	69.64	91.43	Low
21-0000	community and social service occupations	21-1090	miscellaneous community and social service specialists	83.3	3.72	76.02	90.97	Low
21-0000	community and social service occupations	21-2010	clergy	80.4	5.57	69.14	91.52	Low
21-0000	community and social service occupations	21-2020	directors, religious activities and education	80.8	5.53	69.92	91.48	Low
21-0000	community and social service occupations	21-2090	miscellaneous religious workers	80.5	5.55	70.1	91.58	Low
25-0000	education, training, and library occupations	25-1010	business teachers, postsecondary	78.7	5.19	68.84	88.94	Low
25-0000	education, training, and library occupations	25-1020	math and computer teachers, postsecondary	78.7	5.18	68.76	88.87	Low
25-0000	education, training, and library occupations	25-1030	engineering and architecture teachers, postsecondary	78.4	5.28	68.13	89.12	Low
25-0000	education, training, and library occupations	25-1040	life sciences teachers, postsecondary	78.5	5.38	67.7	89.39	Low
25-0000	education, training, and library occupations	25-1050	physical sciences teachers, postsecondary	78.4	5.15	68.58	89.07	Low

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
25-0000	education, training, and library occupations	25-1060	social sciences teachers, postsecondary	78.5	5.28	68.5	89.43	Low
25-0000	education, training, and library occupations	25-1070	health teachers, postsecondary	78.5	5.02	68.62	88.52	Low
25-0000	education, training, and library occupations	25-1080	education and library science teachers, postsecondary	78.4	5.09	68.75	88.83	Low
25-0000	education, training, and library occupations	25-1110	law, criminal justice, and social work teachers, postsecondary	78.5	5.02	68.59	88.74	Low
25-0000	education, training, and library occupations	25-1120	arts, communications, and humanities teachers, postsecondary	78.6	5.21	68.18	89.16	Low
25-0000	education, training, and library occupations	25-1190	miscellaneous postsecondary teachers	78.5	5.14	68.64	88.75	Low
25-0000	education, training, and library occupations	25-2010	preschool and kindergarten teachers	78.6	5.16	68.69	88.31	Low
25-0000	education, training, and library occupations	25-2020	elementary and middle school teachers	78.5	5	68.71	88.28	Low
25-0000	education, training, and library occupations	25-2030	secondary school teachers	81.1	0.79	79.53	82.62	Moderate
25-0000	education, training, and library occupations	25-2050	special education teachers	78.5	5.16	68.21	88.36	Low
25-0000	education, training, and library occupations	25-3010	adult basic and secondary education and literacy teachers and instructors	85.3	1.68	81.89	88.55	Moderate
25-0000	education, training, and library occupations	25-3020	self-enrichment education teachers	80.3	4.47	71.8	89.13	Low
25-0000	education, training, and library occupations	25-3090	miscellaneous teachers and instructors	78.6	5.15	68.29	88.67	Low
25-0000	education, training, and library occupations	25-4010	archivists, curators, and museum technicians	78.6	5.16	68.66	89.23	Low
25-0000	education, training, and library occupations	25-4020	librarians	78.7	5.19	68.45	88.58	Low
25-0000	education, training, and library occupations	25-4030	library technicians	61.0	0.67	59.73	62.27	High
25-0000	education, training, and library occupations	25-9010	audio-visual and multimedia collections specialists	78.7	5.28	68.17	89.25	Low
25-0000	education, training, and library occupations	25-9020	farm and home management advisors	78.6	5.22	68.18	88.71	Low
25-0000	education, training, and library occupations	25-9030	instructional coordinators	78.5	5.22	68.35	88.8	Low
25-0000	education, training, and library occupations	25-9040	teacher assistants	78.7	5.25	68.52	88.66	Low
25-0000	education, training, and library occupations	25-9090	miscellaneous education, training, and library workers	78.6	5.3	68.21	88.96	Low
27-0000	arts, design, entertainment, sports, and media occupations	27-1010	artists and related workers	84.7	0.76	83.17	86.08	High
27-0000	arts, design, entertainment, sports, and media occupations	27-1020	designers	83.3	5.03	73.3	93.32	Low
27-0000	arts, design, entertainment, sports, and media occupations	27-2010	actors, producers, and directors	83.5	5.3	73.08	93.94	Low

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
27-0000	arts, design, entertainment, sports, and media occupations	27-2020	athletes, coaches, umpires, and related workers	87.0	1.18	84.74	89.36	Moderate
27-0000	arts, design, entertainment, sports, and media occupations	27-2030	dancers and choreographers	83.6	4.95	73.88	93.36	Low
27-0000	arts, design, entertainment, sports, and media occupations	27-2040	musicians, singers, and related workers	88.2	1.17	85.85	90.48	Moderate
27-0000	arts, design, entertainment, sports, and media occupations	27-3020	news analysts, reporters and correspondents	77.5	3.38	70.53	84.08	Low
27-0000	arts, design, entertainment, sports, and media occupations	27-3030	public relations specialists	85.5	1.37	82.7	88.09	Moderate
27-0000	arts, design, entertainment, sports, and media occupations	27-3040	writers and editors	83.5	5.02	73.68	93.05	Low
27-0000	arts, design, entertainment, sports, and media occupations	27-3090	miscellaneous media and communication workers	83.7	4.93	74.03	93.72	Low
27-0000	arts, design, entertainment, sports, and media occupations	27-4010	broadcast and sound engineering technicians and radio operators	79.9	3.64	72.79	86.83	Low
27-0000	arts, design, entertainment, sports, and media occupations	27-4020	photographers	83.5	5.04	73.7	93.45	Low
27-0000	arts, design, entertainment, sports, and media occupations	27-4030	television, video, and motion picture camera operators and editors	84.7	3.76	77.21	92.08	Low
27-0000	arts, design, entertainment, sports, and media occupations	27-4090	miscellaneous media and communication equipment workers	83.5	5.16	73.16	93.94	Low
29-0000	healthcare practitioners and technical occupations	29-1010	chiropractors	81.6	4.95	71.59	91.24	Low
29-0000	healthcare practitioners and technical occupations	29-1020	dentists	87.9	1.04	85.88	90	Moderate
29-0000	healthcare practitioners and technical occupations	29-1030	dietitians and nutritionists	81.5	5.01	72.03	91.11	Low
29-0000	healthcare practitioners and technical occupations	29-1040	optometrists	81.7	4.99	71.94	91.25	Low
29-0000	healthcare practitioners and technical occupations	29-1050	pharmacists	81.5	5.11	71.29	91.18	Low
29-0000	healthcare practitioners and technical occupations	29-1060	physicians and surgeons	86.4	2.77	81.15	91.93	Moderate
29-0000	healthcare practitioners and technical occupations	29-1070	physician assistants	81.6	5.12	71.5	91.49	Low
29-0000	healthcare practitioners and technical occupations	29-1080	podiatrists	81.6	5.09	71.43	91.45	Low
29-0000	healthcare practitioners and technical occupations	29-1120	therapists	81.5	5.05	71.56	91.53	Low
29-0000	healthcare practitioners and technical occupations	29-1130	veterinarians	85.9	1.51	83.03	88.93	Moderate

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
29-0000	healthcare practitioners and technical occupations	29-1140	registered nurses	81.5	4.99	71.53	91.08	Low
29-0000	healthcare practitioners and technical occupations	29-1150	nurse anesthetists	81.5	5.09	71.53	91.42	Low
29-0000	healthcare practitioners and technical occupations	29-1160	nurse midwives	81.5	4.98	71.77	91.69	Low
29-0000	healthcare practitioners and technical occupations	29-1170	nurse practitioners	78.7	4.09	70.9	86.59	Low
29-0000	healthcare practitioners and technical occupations	29-1180	audiologists	81.6	4.88	72.06	91.26	Low
29-0000	healthcare practitioners and technical occupations	29-1190	miscellaneous health diagnosing and treating practitioners	81.4	5.1	71.39	91.64	Low
29-0000	healthcare practitioners and technical occupations	29-2010	clinical laboratory technologists and technicians	81.4	4.9	71.62	91.36	Low
29-0000	healthcare practitioners and technical occupations	29-2020	dental hygienists	81.4	5.02	71.86	91.53	Low
29-0000	healthcare practitioners and technical occupations	29-2030	diagnostic related technologists and technicians	81.3	5.05	71.35	91.37	Low
29-0000	healthcare practitioners and technical occupations	29-2040	emergency medical technicians and paramedics	93.0	2.81	87.58	98.39	Moderate
29-0000	healthcare practitioners and technical occupations	29-2050	health practitioner support technologists and technicians	71.5	1.09	69.39	73.68	Moderate
29-0000	healthcare practitioners and technical occupations	29-2060	licensed practical and licensed vocational nurses	71.5	0.96	69.7	73.38	Moderate
29-0000	healthcare practitioners and technical occupations	29-2070	medical records and health information technicians	81.5	5.15	71.68	91.57	Low
29-0000	healthcare practitioners and technical occupations	29-2080	opticians, dispensing	81.3	4.94	71.88	91.21	Low
29-0000	healthcare practitioners and technical occupations	29-2090	miscellaneous health technologists and technicians	81.6	5.19	71.47	91.76	Low
29-0000	healthcare practitioners and technical occupations	29-9010	occupational health and safety specialists and technicians	76.3	0.77	74.68	77.78	Moderate
29-0000	healthcare practitioners and technical occupations	29-9090	miscellaneous health practitioners and technical workers	81.7	5.18	71.65	92.45	Low
31-0000	healthcare support occupations	31-1010	nursing, psychiatric, and home health aides	82.1	5.48	71.39	92.87	Low
31-0000	healthcare support occupations	31-2010	occupational therapy assistants and aides	82.0	5.49	70.76	92.58	Low
31-0000	healthcare support occupations	31-2020	physical therapist assistants and aides	82.0	5.56	70.96	92.26	Low
31-0000	healthcare support occupations	31-9010	massage therapists	82.3	5.58	71.46	93.3	Low
31-0000	healthcare support occupations	31-9090	miscellaneous healthcare support occupations	82.3	1.22	79.89	84.56	Moderate
33-0000	protective service occupations	33-1010	first-line supervisors of law enforcement workers	72.0	0.75	70.52	73.52	High
33-0000	protective service occupations	33-1020	first-line supervisors of fire fighting and prevention workers	79.8	5.04	70.08	89.66	Low
33-0000	protective service occupations	33-1090	miscellaneous first-line supervisors, protective service workers	79.7	5.02	70.25	89.89	Low
33-0000	protective service occupations	33-2010	firefighters	83.5	1.14	81.33	85.79	Moderate

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
33-0000	protective service occupations	33-2020	fire inspectors	79.5	4.95	69.94	89.39	Low
33-0000	protective service occupations	33-3010	bailiffs, correctional officers, and jailers	81.5	0.83	79.96	83.11	Moderate
33-0000	protective service occupations	33-3020	detectives and criminal investigators	69.0	2.21	64.72	73.25	Moderate
33-0000	protective service occupations	33-3030	fish and game wardens	79.7	5.06	69.78	89.76	Low
33-0000	protective service occupations	33-3040	parking enforcement workers	79.8	5.07	69.78	89.78	Low
33-0000	protective service occupations	33-3050	police officers	85.4	0.64	84.15	86.6	High
33-0000	protective service occupations	33-9010	animal control workers	81.1	2.2	76.74	85.38	Moderate
33-0000	protective service occupations	33-9020	private detectives and investigators	79.7	5.01	69.96	89.63	Low
33-0000	protective service occupations	33-9030	security guards and gaming surveillance officers	81.3	1.29	78.81	83.81	Moderate
35-0000	food preparation and serving related occupations	35-1010	supervisors of food preparation and serving workers	82.2	2.27	77.74	86.69	Moderate
35-0000	food preparation and serving related occupations	35-2010	cooks	81.0	1.3	78.57	83.65	Moderate
35-0000	food preparation and serving related occupations	35-2020	food preparation workers	82.9	0.91	81.12	84.69	Moderate
35-0000	food preparation and serving related occupations	35-3010	bartenders	84.8	1.09	82.7	86.9	Moderate
35-0000	food preparation and serving related occupations	35-3020	fast food and counter workers	78.8	1.64	75.69	82.02	Moderate
35-0000	food preparation and serving related occupations	35-3030	waiters and waitresses	84.8	1.7	81.48	88.21	Moderate
35-0000	food preparation and serving related occupations	35-3040	food servers, nonrestaurant	82.6	1.21	80.22	84.97	Moderate
35-0000	food preparation and serving related occupations	35-9010	dining room and cafeteria attendants and bartender helpers	81.6	1.2	79.28	83.92	Moderate
35-0000	food preparation and serving related occupations	35-9020	dishwashers	86.3	1.08	84.16	88.49	Moderate
35-0000	food preparation and serving related occupations	35-9030	hosts and hostesses, restaurant, lounge, and coffee shop	82.7	4.72	73.62	92.22	Low
35-0000	food preparation and serving related occupations	35-9090	miscellaneous food preparation and serving related workers	83.3	2.43	78.59	87.91	Moderate
37-0000		37-1010		84.5	5.37	73.72	94.69	Low

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
	building and grounds cleaning and maintenance		first-line supervisors of building and grounds cleaning and maintenance workers					
37-0000	building and grounds cleaning and maintenance	37-2010	building cleaning workers	87.1	0.21	86.67	87.49	High
37-0000	building and grounds cleaning and maintenance	37-2020	pest control workers	84.4	5.41	73.86	94.82	Low
37-0000	building and grounds cleaning and maintenance	37-3010	grounds maintenance workers	86.9	0.42	86.06	87.75	High
39-0000	personal care and service occupations	39-1010	first-line supervisors of gaming workers	84.6	5.08	74.69	94.68	Low
39-0000	personal care and service occupations	39-2010	animal trainers	84.5	5.16	74.14	94.62	Low
39-0000	personal care and service occupations	39-2020	nonfarm animal caretakers	83.6	2.16	79.53	87.97	Moderate
39-0000	personal care and service occupations	39-3010	gaming services workers	89.6	0.96	87.74	91.46	Moderate
39-0000	personal care and service occupations	39-3020	motion picture projectionists	84.4	4.9	74.77	94.07	Low
39-0000	personal care and service occupations	39-3030	ushers, lobby attendants, and ticket takers	89.6	1.3	87.08	92.05	Moderate
39-0000	personal care and service occupations	39-3090	miscellaneous entertainment attendants and related workers	84.4	1.44	81.62	87.35	Moderate
39-0000	personal care and service occupations	39-4010	embalmers	84.4	5.16	73.99	94.31	Low
39-0000	personal care and service occupations	39-4020	funeral attendants	84.6	4.94	74.42	94.37	Low
39-0000	personal care and service occupations	39-4030	morticians, undertakers, and funeral directors	84.7	5.03	75.32	94.9	Low
39-0000	personal care and service occupations	39-5010	barbers, hairdressers, hairstylists and cosmetologists	84.6	2.82	79.03	90.15	Moderate
39-0000	personal care and service occupations	39-5090	miscellaneous personal appearance workers	84.5	4.99	74.99	94.56	Low
39-0000	personal care and service occupations	39-6010	baggage porters, bellhops, and concierges	80.7	2.4	75.66	85.28	Moderate
39-0000	personal care and service occupations	39-7010	tour and travel guides	84.6	5.15	74.55	95.01	Low
39-0000	personal care and service occupations	39-9010	childcare workers	83.2	4.08	75.16	91.59	Low
39-0000	personal care and service occupations	39-9020	personal care aides	84.7	5.14	74.77	95	Low
39-0000	personal care and service occupations	39-9040	residential advisors	84.4	5.04	74.33	94.07	Low
39-0000	personal care and service occupations	39-9090	miscellaneous personal care and service workers	84.5	5	75.07	94.17	Low
41-0000	sales and related occupations	41-1010	first-line supervisors of sales workers	82.0	1.24	79.65	84.38	Moderate
41-0000	sales and related occupations	41-2010	cashiers	77.5	1.52	74.55	80.58	Moderate
41-0000	sales and related occupations	41-2020	counter and rental clerks and parts salespersons	81.1	5.13	71.07	91.04	Low

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
41-0000	sales and related occupations	41-2030	retail salespersons	84.1	0.85	82.45	85.81	Moderate
41-0000	sales and related occupations	41-3010	advertising sales agents	81.2	5.12	71.28	90.82	Low
41-0000	sales and related occupations	41-3020	insurance sales agents	81.0	5.02	71.03	90.82	Low
41-0000	sales and related occupations	41-3030	securities, commodities, and financial services sales agents	81.2	4.99	71.52	91.27	Low
41-0000	sales and related occupations	41-3040	travel agents	81.2	5.11	71.21	90.87	Low
41-0000	sales and related occupations	41-3090	miscellaneous sales representatives, services	81.4	5.04	71.72	91.05	Low
41-0000	sales and related occupations	41-4010	sales representatives, wholesale and manufacturing	74.4	2.64	69.16	79.59	Moderate
41-0000	sales and related occupations	41-9010	models, demonstrators, and product promoters	81.3	5.21	70.91	91.56	Low
41-0000	sales and related occupations	41-9020	real estate brokers and sales agents	81.3	5.06	71.47	91.27	Low
41-0000	sales and related occupations	41-9030	sales engineers	81.2	5.05	71.28	91.3	Low
41-0000	sales and related occupations	41-9040	telemarketers	81.3	5.04	71.36	91.4	Low
41-0000	sales and related occupations	41-9090	miscellaneous sales and related workers	85.6	0.31	85.04	86.27	High
43-0000	office and administrative support occupations	43-1010	first-line supervisors of office and administrative support workers	79.8	1.17	77.58	82.15	Moderate
43-0000	office and administrative support occupations	43-2010	switchboard operators, including answering service	78.7	4.75	69.33	88.07	Low
43-0000	office and administrative support occupations	43-2020	telephone operators	78.7	4.78	69.58	88.39	Low
43-0000	office and administrative support occupations	43-2090	miscellaneous communications equipment operators	85.6	0.94	83.66	87.34	Moderate
43-0000	office and administrative support occupations	43-3010	bill and account collectors	78.7	4.72	69.35	88.17	Low
43-0000	office and administrative support occupations	43-3020	billing and posting clerks	78.8	4.87	69.6	88.47	Low
43-0000	office and administrative support occupations	43-3030	bookkeeping, accounting, and auditing clerks	83.0	3.55	75.92	89.86	Low
43-0000	office and administrative support occupations	43-3040	gaming cage workers	78.7	4.8	69.39	88.11	Low
43-0000	office and administrative support occupations	43-3050	payroll and timekeeping clerks	75.0	1.55	71.91	78.08	Moderate
43-0000	office and administrative support occupations	43-3060	procurement clerks	78.9	4.79	69.67	88.21	Low
43-0000	office and administrative support occupations	43-3070	tellers	78.9	4.75	69.46	87.94	Low
43-0000	office and administrative support occupations	43-3090	miscellaneous financial clerks	78.6	4.81	69.62	88.29	Low
43-0000	office and administrative support occupations	43-4010	brokerage clerks	78.8	4.88	69.35	88.4	Low
43-0000	office and administrative support occupations	43-4020	correspondence clerks	78.8	4.9	69.81	88.54	Low

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
43-0000	office and administrative support occupations	43-4030	court, municipal, and license clerks	78.8	4.89	69.14	88.38	Low
43-0000	office and administrative support occupations	43-4040	credit authorizers, checkers, and clerks	78.8	4.82	69.45	87.72	Low
43-0000	office and administrative support occupations	43-4050	customer service representatives	78.6	0.77	77.18	80.08	High
43-0000	office and administrative support occupations	43-4060	eligibility interviewers, government programs	78.8	4.85	69.22	88.18	Low
43-0000	office and administrative support occupations	43-4070	file clerks	78.7	4.81	69.41	88.16	Low
43-0000	office and administrative support occupations	43-4080	hotel, motel, and resort desk clerks	80.3	1.18	78.07	82.53	Moderate
43-0000	office and administrative support occupations	43-4110	interviewers, except eligibility and loan	78.7	4.81	69.26	87.95	Low
43-0000	office and administrative support occupations	43-4120	library assistants, clerical	79.0	4.93	69.18	88.75	Low
43-0000	office and administrative support occupations	43-4130	loan interviewers and clerks	78.8	4.94	69.03	88.38	Low
43-0000	office and administrative support occupations	43-4140	new accounts clerks	78.7	4.95	69.16	88.67	Low
43-0000	office and administrative support occupations	43-4150	order clerks	78.8	4.77	69.34	88.02	Low
43-0000	office and administrative support occupations	43-4160	human resources assistants, except payroll and timekeeping	78.8	4.82	69.14	88.09	Low
43-0000	office and administrative support occupations	43-4170	receptionists and information clerks	78.8	4.78	69.29	87.95	Low
43-0000	office and administrative support occupations	43-4180	reservation and transportation ticket agents and travel clerks	76.8	1.62	73.61	79.93	Moderate
43-0000	office and administrative support occupations	43-4190	miscellaneous information and record clerks	78.9	4.85	69.46	88.14	Low
43-0000	office and administrative support occupations	43-5010	cargo and freight agents	82.7	0.97	80.78	84.6	Moderate
43-0000	office and administrative support occupations	43-5020	couriers and messengers	78.8	4.89	69.14	87.85	Low
43-0000	office and administrative support occupations	43-5030	dispatchers	77.1	0.78	75.53	78.56	Moderate
43-0000	office and administrative support occupations	43-5040	meter readers, utilities	78.8	4.99	69.45	88.7	Low
43-0000	office and administrative support occupations	43-5050	postal service workers	82.2	1.27	79.67	84.72	Moderate
43-0000	office and administrative support occupations	43-5060	production, planning, and expediting clerks	81.0	2.87	75.15	86.38	Moderate
43-0000	office and administrative support occupations	43-5070	shipping, receiving, and traffic clerks	77.1	0.42	76.36	77.98	High
43-0000	office and administrative support occupations	43-5080	stock clerks and order fillers	80.3	0.29	79.73	80.88	High
43-0000	office and administrative support occupations	43-5110	weighers, measurers, checkers, and samplers, recordkeeping	71.2	0.62	69.98	72.38	High
43-0000	office and administrative support occupations	43-6010	secretaries and administrative assistants	78.9	4.88	69.69	88.65	Low
43-0000	office and administrative support occupations	43-9010	computer operators	78.9	4.78	69.6	88.4	Low

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
43-0000	office and administrative support occupations	43-9030	desktop publishers	78.7	4.78	69.26	87.77	Low
43-0000	office and administrative support occupations	43-9040	insurance claims and policy processing clerks	78.7	4.87	69.26	88.53	Low
43-0000	office and administrative support occupations	43-9050	mail clerks and mail machine operators, except postal service	78.7	4.85	69.15	87.88	Low
43-0000	office and administrative support occupations	43-9060	office clerks, general	70.7	1.38	67.98	73.41	Moderate
43-0000	office and administrative support occupations	43-9070	office machine operators, except computer	81.1	3.07	75.31	87.14	Moderate
43-0000	office and administrative support occupations	43-9080	proofreaders and copy markers	78.8	4.75	69.74	88.22	Low
43-0000	office and administrative support occupations	43-9110	statistical assistants	77.5	0.79	75.89	78.99	Moderate
43-0000	office and administrative support occupations	43-9190	miscellaneous office and administrative support workers	73.3	1.08	71.22	75.38	Moderate
45-0000	farming, fishing, and forestry occupations	45-1010	first-line supervisors of farming, fishing, and forestry workers	86.6	4.96	76.63	96.54	Low
45-0000	farming, fishing, and forestry occupations	45-2010	agricultural inspectors	80.4	1.09	78.35	82.59	Moderate
45-0000	farming, fishing, and forestry occupations	45-2020	animal breeders	91.9	0.71	90.49	93.25	High
45-0000	farming, fishing, and forestry occupations	45-2040	graders and sorters, agricultural products	85.6	1.75	82.24	89.03	Moderate
45-0000	farming, fishing, and forestry occupations	45-2090	miscellaneous agricultural workers	90.9	0.29	90.36	91.48	High
45-0000	farming, fishing, and forestry occupations	45-3010	fishers and related fishing workers	87.6	1.48	84.67	90.52	Moderate
45-0000	farming, fishing, and forestry occupations	45-3020	hunters and trappers	86.4	4.94	76.71	96.35	Low
45-0000	farming, fishing, and forestry occupations	45-4010	forest and conservation workers	86.4	4.95	76.78	96.17	Low
45-0000	farming, fishing, and forestry occupations	45-4020	logging workers	89.6	0.5	88.59	90.62	High
47-0000	construction and extraction occupations	47-1010	first-line supervisors of construction trades and extraction workers	78.3	0.11	78.05	78.47	High
47-0000	construction and extraction occupations	47-2010	boilermakers	84.3	1.04	82.31	86.42	Moderate
47-0000	construction and extraction occupations	47-2020	brickmasons, blockmasons, and stonemasons	86.5	0.32	85.83	87.09	High
47-0000	construction and extraction occupations	47-2030	carpenters	84.7	0.17	84.35	84.99	High
47-0000	construction and extraction occupations	47-2040	carpet, floor, and tile installers and finishers	87.9	0.68	86.65	89.25	High
47-0000	construction and extraction occupations	47-2050	cement masons, concrete finishers, and terrazzo workers	87.6	0.31	87	88.22	High
47-0000	construction and extraction occupations	47-2060	construction laborers	89.0	0.21	88.63	89.45	High
47-0000	construction and extraction occupations	47-2070	construction equipment operators	86.4	0.23	85.94	86.81	High
47-0000	construction and extraction occupations	47-2110	electricians	78.3	0.11	78.06	78.49	High

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
47-0000	construction and extraction occupations	47-2120	glaziers	84.5	1.22	82.12	86.81	Moderate
47-0000	construction and extraction occupations	47-2130	insulation workers	84.6	1.42	81.69	87.33	Moderate
47-0000	construction and extraction occupations	47-2140	painters and paperhangers	82.2	0.93	80.38	84.05	Moderate
47-0000	construction and extraction occupations	47-2150	pipelayers, plumbers, pipefitters, and steamfitters	82.4	0.15	82.08	82.67	High
47-0000	construction and extraction occupations	47-2160	plasterers and stucco masons	83.5	4.78	74.39	92.79	Low
47-0000	construction and extraction occupations	47-2170	reinforcing iron and rebar workers	84.9	1.92	81.05	88.72	Moderate
47-0000	construction and extraction occupations	47-2180	roofers	89.1	0.65	87.85	90.36	High
47-0000	construction and extraction occupations	47-2210	sheet metal workers	85.1	0.22	84.65	85.48	High
47-0000	construction and extraction occupations	47-2220	structural iron and steel workers	80.9	0.79	79.37	82.46	Moderate
47-0000	construction and extraction occupations	47-3010	helpers, construction trades	79.6	0.39	78.84	80.3	High
47-0000	construction and extraction occupations	47-4010	construction and building inspectors	83.7	4.81	74.32	93.28	Low
47-0000	construction and extraction occupations	47-4020	elevator installers and repairers	83.5	4.8	73.96	92.93	Low
47-0000	construction and extraction occupations	47-4030	fence erectors	83.6	4.87	74.17	93.39	Low
47-0000	construction and extraction occupations	47-4040	hazardous materials removal workers	75.3	1.12	73.24	77.51	Moderate
47-0000	construction and extraction occupations	47-4050	highway maintenance workers	83.5	4.79	74.3	92.92	Low
47-0000	construction and extraction occupations	47-4060	rail-track laying and maintenance equipment operators	80.5	0.61	79.38	81.74	High
47-0000	construction and extraction occupations	47-4070	septic tank servicers and sewer pipe cleaners	85.6	1.1	83.48	87.76	Moderate
47-0000	construction and extraction occupations	47-4090	miscellaneous construction and related workers	81.6	0.57	80.5	82.71	High
47-0000	construction and extraction occupations	47-5020	earth drillers, except oil and gas	82.3	0.07	82.22	82.48	High
47-0000	construction and extraction occupations	47-5030	explosives workers, ordnance handling experts, and blasters	85.5	0.21	85.04	85.86	High
47-0000	construction and extraction occupations	47-5040	mining machine operators	82.7	0.02	82.7	82.76	High
47-0000	construction and extraction occupations	47-5050	rock splitters, quarry	84.0	0.11	83.81	84.27	High
47-0000	construction and extraction occupations	47-5060	roof bolters, mining	84.1	0.04	84.04	84.22	High
47-0000	construction and extraction occupations	47-5070	roustabouts, oil and gas	83.7	4.82	73.81	93.19	Low
47-0000	construction and extraction occupations	47-5080	helpers--extraction workers	83.9	0.07	83.72	84	High
47-0000	construction and extraction occupations	47-5090	miscellaneous extraction workers	85.1	0.23	84.61	85.5	High

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
49-0000	installation, maintenance, and repair occupations	49-1010	first-line supervisors of mechanics, installers, and repairers	83.2	0.65	81.85	84.45	High
49-0000	installation, maintenance, and repair occupations	49-2010	computer, automated teller, and office machine repairers	83.3	4.83	74.19	92.86	Low
49-0000	installation, maintenance, and repair occupations	49-2020	radio and telecommunications equipment installers and repairers	84.8	0.98	82.97	86.83	Moderate
49-0000	installation, maintenance, and repair occupations	49-2090	miscellaneous electrical and electronic equipment mechanics, installers, and repairers	77.0	1.62	73.99	80.41	Moderate
49-0000	installation, maintenance, and repair occupations	49-3010	aircraft mechanics and service technicians	87.2	1.04	85.03	89.19	Moderate
49-0000	installation, maintenance, and repair occupations	49-3020	automotive technicians and repairers	83.7	0.28	83.21	84.28	High
49-0000	installation, maintenance, and repair occupations	49-3030	bus and truck mechanics and diesel engine specialists	83.2	1.07	81.11	85.26	Moderate
49-0000	installation, maintenance, and repair occupations	49-3040	heavy vehicle and mobile equipment service technicians and mechanics	78.8	0.08	78.68	78.98	High
49-0000	installation, maintenance, and repair occupations	49-3050	small engine mechanics	86.3	1.54	83.27	89.3	Moderate
49-0000	installation, maintenance, and repair occupations	49-3090	miscellaneous vehicle and mobile equipment mechanics, installers, and repairers	87.4	1.06	85.48	89.49	Moderate
49-0000	installation, maintenance, and repair occupations	49-9010	control and valve installers and repairers	88.8	2.23	84.53	93.11	Moderate
49-0000	installation, maintenance, and repair occupations	49-9020	heating, air conditioning, and refrigeration mechanics and installers	87.7	1	85.74	89.57	Moderate
49-0000	installation, maintenance, and repair occupations	49-9030	home appliance repairers	83.5	4.88	73.87	92.92	Low
49-0000	installation, maintenance, and repair occupations	49-9040	industrial machinery installation, repair, and maintenance workers	84.6	0.11	84.35	84.77	High
49-0000	installation, maintenance, and repair occupations	49-9050	line installers and repairers	81.6	0.77	80.08	83.06	High
49-0000	installation, maintenance, and repair occupations	49-9060	precision instrument and equipment repairers	75.8	2	71.83	79.58	Moderate
49-0000	installation, maintenance, and repair occupations	49-9070	maintenance and repair workers, general	81.6	0.06	81.5	81.73	High
49-0000	installation, maintenance, and repair occupations	49-9080	wind turbine service technicians	83.3	4.9	73.63	92.77	Low
49-0000	installation, maintenance, and repair occupations	49-9090	miscellaneous installation, maintenance, and repair workers	84.2	0.61	83.01	85.41	High
51-0000	production occupations	51-1010	first-line supervisors of production and operating workers	82.2	0.09	81.98	82.33	High
51-0000	production occupations	51-2010	aircraft structure, surfaces, rigging, and systems assemblers	85.6	4.75	76.4	95.38	Low
51-0000	production occupations	51-2020	electrical, electronics, and electromechanical assemblers	85.1	0.31	84.54	85.72	High
51-0000	production occupations	51-2030	engine and other machine assemblers	85.3	4.77	75.73	94.51	Low
51-0000	production occupations	51-2040	structural metal fabricators and fitters	86.7	0.18	86.35	87.05	High
51-0000	production occupations	51-2090	miscellaneous assemblers and fabricators	82.7	0.05	82.59	82.79	High
51-0000	production occupations	51-3010	bakers	83.9	0.82	82.31	85.57	Moderate

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
51-0000	production occupations	51-3020	butchers and other meat, poultry, and fish processing workers	90.6	0.21	90.18	90.98	High
51-0000	production occupations	51-3090	miscellaneous food processing workers	88.4	0.16	88.12	88.74	High
51-0000	production occupations	51-4010	computer control programmers and operators	78.6	0.96	76.82	80.51	Moderate
51-0000	production occupations	51-4020	forming machine setters, operators, and tenders, metal and plastic	91.2	0.27	90.69	91.76	High
51-0000	production occupations	51-4030	machine tool cutting setters, operators, and tenders, metal and plastic	87.6	0.07	87.45	87.74	High
51-0000	production occupations	51-4040	machinists	80.9	0.12	80.67	81.16	High
51-0000	production occupations	51-4050	metal furnace operators, tenders, pourers, and casters	87.9	0.22	87.43	88.29	High
51-0000	production occupations	51-4060	model makers and patternmakers, metal and plastic	85.1	0.78	83.56	86.67	Moderate
51-0000	production occupations	51-4070	molders and molding machine setters, operators, and tenders, metal and plastic	88.2	0.21	87.76	88.56	High
51-0000	production occupations	51-4080	multiple machine tool setters, operators, and tenders, metal and plastic	88.3	0.17	87.96	88.64	High
51-0000	production occupations	51-4110	tool and die makers	82.1	0.19	81.75	82.48	High
51-0000	production occupations	51-4120	welding, soldering, and brazing workers	85.0	0.08	84.83	85.13	High
51-0000	production occupations	51-4190	miscellaneous metal workers and plastic workers	89.2	0.09	88.98	89.35	High
51-0000	production occupations	51-5110	printing workers	84.0	0.29	83.42	84.58	High
51-0000	production occupations	51-6010	laundry and dry-cleaning workers	83.2	0.75	81.69	84.65	High
51-0000	production occupations	51-6020	pressers, textile, garment, and related materials	89.7	0.3	89.05	90.24	High
51-0000	production occupations	51-6030	sewing machine operators	81.3	1.21	78.88	83.63	Moderate
51-0000	production occupations	51-6040	shoe and leather workers	89.1	0.45	88.2	89.93	High
51-0000	production occupations	51-6050	tailors, dressmakers, and sewers	90.8	1.05	88.75	92.73	Moderate
51-0000	production occupations	51-6060	textile machine setters, operators, and tenders	89.9	0.18	89.56	90.27	High
51-0000	production occupations	51-6090	miscellaneous textile, apparel, and furnishings workers	88.1	0.27	87.55	88.65	High
51-0000	production occupations	51-7010	cabinetmakers and bench carpenters	89.4	0.22	89	89.87	High
51-0000	production occupations	51-7020	furniture finishers	83.5	1.53	80.44	86.48	Moderate
51-0000	production occupations	51-7030	model makers and patternmakers, wood	80.8	2.88	75.21	86.61	Moderate
51-0000	production occupations	51-7040	woodworking machine setters, operators, and tenders	92.5	0.07	92.37	92.62	High
51-0000	production occupations	51-7090	miscellaneous woodworkers	90.1	0.21	89.7	90.54	High
51-0000	production occupations	51-8010	power plant operators, distributors, and dispatchers	86.7	0.53	85.66	87.68	High
51-0000	production occupations	51-8020	stationary engineers and boiler operators	86.9	0.76	85.39	88.39	High
51-0000	production occupations	51-8030	water and wastewater treatment plant and system operators	75.9	0.47	75	76.86	High
51-0000	production occupations	51-8090	miscellaneous plant and system operators	82.7	0.43	81.87	83.54	High
51-0000	production occupations	51-9010	chemical processing machine setters, operators, and tenders	83.9	0.13	83.63	84.14	High
51-0000	production occupations	51-9020	crushing, grinding, polishing, mixing, and blending workers	87.5	0.08	87.32	87.63	High

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
51-0000	production occupations	51-9030	cutting workers	85.1	0.13	84.83	85.35	High
51-0000	production occupations	51-9040	extruding, forming, pressing, and compacting machine setters, operators, and tenders	86.2	0.65	84.9	87.44	High
51-0000	production occupations	51-9050	furnace, kiln, oven, drier, and kettle operators and tenders	89.6	0.33	89.01	90.27	High
51-0000	production occupations	51-9060	inspectors, testers, sorters, samplers, and weighers	81.6	0.12	81.39	81.85	High
51-0000	production occupations	51-9070	jewelers and precious stone and metal workers	85.5	4.93	75.95	94.79	Low
51-0000	production occupations	51-9080	medical, dental, and ophthalmic laboratory technicians	68.6	1.62	65.6	71.8	Moderate
51-0000	production occupations	51-9110	packaging and filling machine operators and tenders	86.8	0.19	86.42	87.19	High
51-0000	production occupations	51-9120	painting workers	84.3	0.18	84	84.68	High
51-0000	production occupations	51-9140	semiconductor processors	85.4	4.85	76.11	95.47	Low
51-0000	production occupations	51-9150	photographic process workers and processing machine operators	85.6	4.78	76.42	94.78	Low
51-0000	production occupations	51-9190	miscellaneous production workers	87.6	0.07	87.5	87.76	High
53-0000	transportation and material moving occupations	53-1010	aircraft cargo handling supervisors	83.6	4.91	73.9	92.99	Low
53-0000	transportation and material moving occupations	53-1020	first-line supervisors of helpers, laborers, and material movers, hand	86.7	2.41	81.62	91.41	Moderate
53-0000	transportation and material moving occupations	53-1030	first-line supervisors of transportation and material-moving machine and vehicle operators	78.2	3	72.2	83.73	Moderate
53-0000	transportation and material moving occupations	53-2010	aircraft pilots and flight engineers	87.6	0.88	85.93	89.37	Moderate
53-0000	transportation and material moving occupations	53-2020	air traffic controllers and airfield operations specialists	82.6	0.93	80.81	84.46	Moderate
53-0000	transportation and material moving occupations	53-2030	flight attendants	83.9	4.97	74.2	93.72	Low
53-0000	transportation and material moving occupations	53-3010	ambulance drivers and attendants, except emergency medical technicians	84.7	2.61	79.69	90.03	Moderate
53-0000	transportation and material moving occupations	53-3020	bus drivers	78.0	2.63	72.69	83.14	Moderate
53-0000	transportation and material moving occupations	53-3030	driver/sales workers and truck drivers	81.7	0.03	81.64	81.78	High
53-0000	transportation and material moving occupations	53-3040	taxi drivers and chauffeurs	83.7	4.85	74.34	93	Low
53-0000	transportation and material moving occupations	53-3090	miscellaneous motor vehicle operators	83.7	4.69	74.63	92.77	Low

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
53-0000	transportation and material moving occupations	53-4010	locomotive engineers and operators	82.1	2.35	77.18	86.59	Moderate
53-0000	transportation and material moving occupations	53-4020	railroad brake, signal, and switch operators	82.0	1.08	79.89	84.21	Moderate
53-0000	transportation and material moving occupations	53-4030	railroad conductors and yardmasters	83.6	4.86	73.81	93.32	Low
53-0000	transportation and material moving occupations	53-4040	subway and streetcar operators	83.8	4.8	74.13	92.52	Low
53-0000	transportation and material moving occupations	53-4090	miscellaneous rail transportation workers	83.8	4.95	73.7	93.48	Low
53-0000	transportation and material moving occupations	53-5010	sailors and marine oilers	83.7	4.68	74.53	92.91	Low
53-0000	transportation and material moving occupations	53-5020	ship and boat captains and operators	84.8	0.97	82.88	86.63	Moderate
53-0000	transportation and material moving occupations	53-5030	ship engineers	84.0	4.93	74.43	93.35	Low
53-0000	transportation and material moving occupations	53-6010	bridge and lock tenders	83.6	4.76	74.3	92.9	Low
53-0000	transportation and material moving occupations	53-6020	parking lot attendants	84.0	4.67	74.67	93.03	Low
53-0000	transportation and material moving occupations	53-6040	traffic technicians	81.9	1.34	79.25	84.53	Moderate
53-0000	transportation and material moving occupations	53-6050	transportation inspectors	83.6	4.84	73.78	92.48	Low
53-0000	transportation and material moving occupations	53-6060	transportation attendants, except flight attendants	83.1	0.59	81.98	84.27	High
53-0000	transportation and material moving occupations	53-6090	miscellaneous transportation workers	83.8	4.85	74.2	93.45	Low
53-0000	transportation and material moving occupations	53-7010	conveyor operators and tenders	88.5	0.44	87.63	89.36	High
53-0000	transportation and material moving occupations	53-7020	crane and tower operators	88.1	0.33	87.48	88.78	High
53-0000	transportation and material moving occupations	53-7030	dredge, excavating, and loading machine operators	84.5	0.24	83.98	84.93	High
53-0000	transportation and material moving occupations	53-7040	hoist and winch operators	80.5	1.59	77.26	83.52	Moderate

Table 6 (continued)

Major SOC	Major SOC Title	Broad SOC	Broad SOC Title	Mean (dBA)	Standard deviation	2.5% quantile	97.5% quantile	Confidence
53-0000	transportation and material moving occupations	53-7050	industrial truck and tractor operators	86.6	0.17	86.28	86.98	High
53-0000	transportation and material moving occupations	53-7060	laborers and material movers, hand	84.9	0.07	84.76	85.04	High
53-0000	transportation and material moving occupations	53-7070	pumping station operators	88.2	1.05	86.14	90.32	Moderate
53-0000	transportation and material moving occupations	53-7080	refuse and recyclable material collectors	86.2	0.78	84.74	87.78	Moderate
53-0000	transportation and material moving occupations	53-7110	mine shuttle car operators	79.1	0.37	78.43	79.83	High
53-0000	transportation and material moving occupations	53-7120	tank car, truck, and ship loaders	79.7	0.29	79.13	80.24	High
53-0000	transportation and material moving occupations	53-7190	miscellaneous material moving workers	88.5	0.6	87.33	89.66	High
55-0000	military specific occupations	55-1010	military officer special and tactical operations leaders	77.2	3.33	70.54	83.74	Low
55-0000	military specific occupations	55-2010	first-line enlisted military supervisors	78.8	5.5	68.18	89.09	Low
55-0000	military specific occupations	55-3010	military enlisted tactical operations and air/weapons specialists and crew members	74.5	2.27	70.06	78.86	Moderate

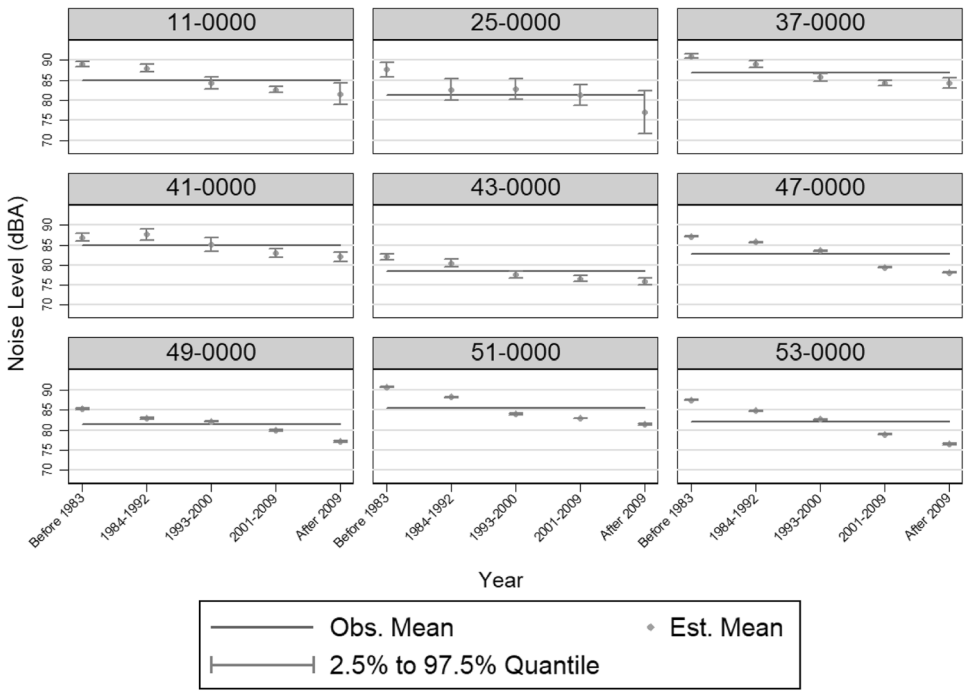

Fig. 6 Major SOCs that are decreasing over time

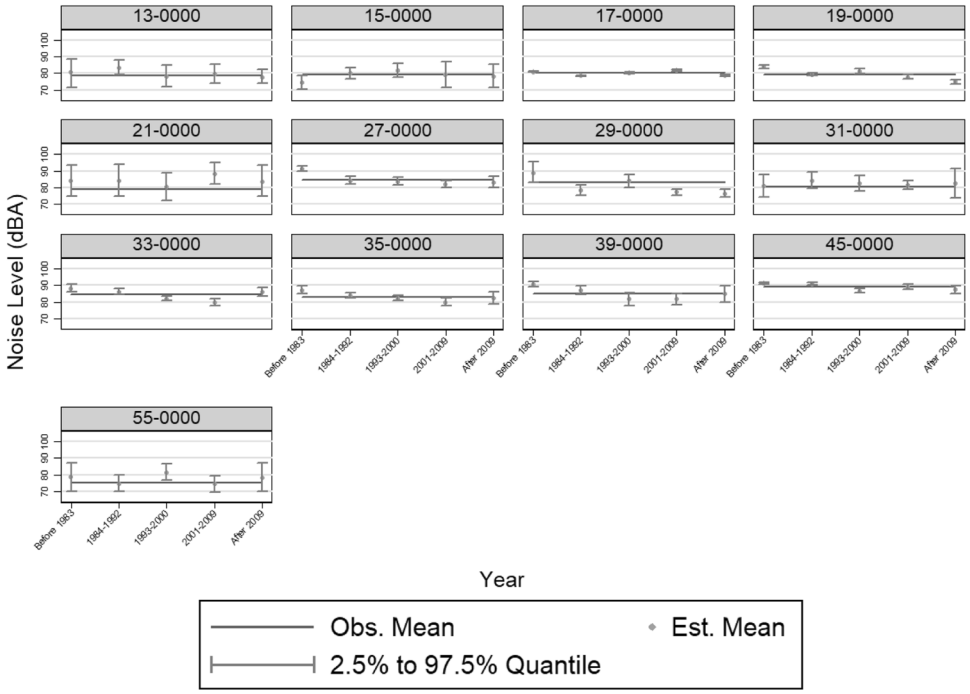

Fig. 7 Major SOCs that are not decreasing over time

Table 7 Full model results for the temporal analysis for major SOCs

Major SOC	Year Group	Obs. Mean	Obs. Median	Obs. SD	Obs. *N*	Est. Mean	Est. SD	Est. 2.5% Quantile	Est. 97.5% Quantile
11-0000	Before 1983	89.0	89.5	6.9	413	89.0	0.3	88.3	89.6
11-0000	1984–1992	88.1	90.0	8.9	358	88.0	0.5	87.1	89.0
11-0000	1993–2000	84.3	84.9	8.6	136	84.3	0.7	82.9	85.7
11-0000	2001–2009	82.7	82.6	8.5	415	82.7	0.4	81.9	83.5
11-0000	After 2009	81.1	79.9	11.3	58	81.6	1.4	78.9	84.3
13-0000	Before 1983					80.5	4.3	71.6	88.4
13-0000	1984–1992	85.1	86.2	7.2	8	83.5	2.2	79.2	87.8
13-0000	1993–2000	73.7	70.3	11.6	5	78.2	3.3	72.1	84.8
13-0000	2001–2009	79.3	78.4	13.0	10	79.9	2.9	74.3	85.6
13-0000	After 2009	76.8	75.0	9.6	16	77.9	2.1	73.9	82.1
15-0000	Before 1983	72.4	72.6	5.6	5	74.6	2.2	70.5	78.9
15-0000	1984–1992	80.3	81.5	6.1	9	80.1	1.8	76.7	83.6
15-0000	1993–2000	82.5	82.0	6.5	7	81.5	2.2	77.4	85.9
15-0000	2001–2009	85.0	85.0		1	79.4	4.1	71.3	87.1
15-0000	After 2009	75.5	69.8	10.3	3	78.3	3.5	71.6	85.1
17-0000	Before 1983	80.8	81.7	8.7	2281	80.8	0.2	80.5	81.2
17-0000	1984–1992	78.5	78.9	7.4	1942	78.5	0.2	78.2	78.8
17-0000	1993–2000	80.3	80.7	7.1	976	80.3	0.2	79.9	80.8
17-0000	2001–2009	81.7	82.2	6.8	1403	81.7	0.2	81.4	82.1
17-0000	After 2009	78.7	79.3	7.0	574	78.8	0.3	78.2	79.4
19-0000	Before 1983	84.0	84.8	8.4	172	83.9	0.6	82.7	85.1
19-0000	1984–1992	79.3	80.5	6.9	272	79.3	0.4	78.5	80.1
19-0000	1993–2000	81.3	81.4	8.0	86	81.3	0.9	79.6	83.0
19-0000	2001–2009	77.6	77.6	7.4	138	77.7	0.7	76.5	79.0
19-0000	After 2009	74.7	73.4	6.9	108	74.9	0.7	73.7	76.2

Table 7 (continued)

Major SOC	Year Group	Obs. Mean	Obs. Median	Obs. SD	Obs. *N*	Est. Mean	Est. SD	Est. 2.5% Quantile	Est. 97.5% Quantile
21-0000	Before 1983	78.0	78.0	0.0	2	84.1	4.8	74.9	93.4
21-0000	1984–1992	74.3	74.3		1	84.0	4.9	74.7	93.8
21-0000	1993–2000	69.6	69.6	9.9	2	80.8	4.1	72.5	88.7
21-0000	2001–2009	94.4	94.4	6.1	2	88.4	3.3	82.0	95.0
21-0000	After 2009					83.9	4.8	74.7	93.5
25-0000	Before 1983	88.1	89.0	5.9	35	87.7	1.0	85.8	89.5
25-0000	1984–1992	82.7	83.3	8.6	38	82.7	1.3	80.1	85.4
25-0000	1993–2000	82.8	85.1	8.6	37	82.8	1.3	80.2	85.4
25-0000	2001–2009	81.0	83.3	9.4	45	81.2	1.3	78.7	83.9
25-0000	After 2009	72.2	68.6	11.0	10	77.0	2.7	71.7	82.3
27-0000	Before 1983	91.6	91.2	6.1	54	91.2	0.8	89.6	92.8
27-0000	1984–1992	84.2	86.6	8.3	48	84.3	1.2	82.0	86.5
27-0000	1993–2000	83.8	86.5	9.0	53	83.9	1.2	81.6	86.1
27-0000	2001–2009	81.8	81.7	7.0	45	82.1	1.0	80.1	84.1
27-0000	After 2009	82.7	80.7	12.0	38	83.1	1.7	79.8	86.6
29-0000	Before 1983	99.1	103.8	16.2	14	88.9	3.1	83.0	95.3
29-0000	1984–1992	78.0	76.8	9.1	35	78.6	1.5	75.6	81.4
29-0000	1993–2000	84.9	86.1	6.3	8	83.9	2.0	80.1	87.6
29-0000	2001–2009	77.0	77.9	8.7	84	77.2	0.9	75.5	79.1
29-0000	After 2009	76.0	73.3	10.9	79	76.5	1.2	74.3	78.9
31-0000	Before 1983	77.8	75.5	14.0	6	81.1	3.4	74.6	87.6
31-0000	1984–1992	85.8	86.6	12.1	16	84.4	2.5	79.5	89.2
31-0000	1993–2000	82.6	79.3	10.0	14	82.5	2.3	78.1	87.0
31-0000	2001–2009	81.3	80.1	7.5	30	81.5	1.3	79.0	84.1
31-0000	After 2009	75.6	75.6		1	82.5	4.4	73.8	91.2
33-0000	Before 1983	88.8	90.5	9.3	58	88.3	1.2	86.0	90.6
33-0000	1984–1992	86.3	87.5	8.2	77	86.2	0.9	84.4	87.9
33-0000	1993–2000	81.9	82.2	8.8	176	82.0	0.7	80.7	83.3
33-0000	2001–2009	79.5	79.3	11.2	104	79.9	1.1	77.9	82.0
33-0000	After 2009	86.4	88.9	11.4	65	86.1	1.3	83.5	88.8
35-0000	Before 1983	87.6	88.3	7.2	32	87.2	1.2	84.8	89.5
35-0000	1984–1992	83.9	84.6	8.4	111	83.8	0.8	82.3	85.3
35-0000	1993–2000	82.3	82.0	8.1	108	82.4	0.8	80.9	83.9
35-0000	2001–2009	79.7	79.9	9.2	54	80.0	1.2	77.7	82.3
35-0000	After 2009	82.1	85.7	8.0	14	82.3	1.9	78.5	85.9
37-0000	Before 1983	91.1	92.0	6.5	424	91.0	0.3	90.4	91.6
37-0000	1984–1992	89.0	89.8	7.5	306	89.0	0.4	88.1	89.9
37-0000	1993–2000	85.8	86.0	8.1	232	85.7	0.5	84.8	86.8
37-0000	2001–2009	84.2	84.0	7.4	565	84.2	0.3	83.7	84.9
37-0000	After 2009	84.3	84.9	7.9	148	84.4	0.7	83.1	85.6
39-0000	Before 1983	90.8	92.4	6.9	76	90.5	0.8	88.9	92.1
39-0000	1984–1992	87.3	88.0	8.3	37	87.0	1.3	84.4	89.5
39-0000	1993–2000	80.7	80.0	10.7	23	81.8	2.0	78.0	85.7
39-0000	2001–2009	81.0	80.7	8.6	23	81.7	1.7	78.5	85.1
39-0000	After 2009	84.9	86.2	13.1	19	84.8	2.5	79.8	89.4
41-0000	Before 1983	87.0	87.6	7.6	195	86.9	0.5	85.9	88.0
41-0000	1984–1992	87.7	89.2	9.2	177	87.6	0.7	86.3	89.0

Table 7 (continued)

Major SOC	Year Group	Obs. Mean	Obs. Median	Obs. SD	Obs. *N*	Est. Mean	Est. SD	Est. 2.5% Quantile	Est. 97.5% Quantile
41-0000	1993–2000	85.3	87.6	10.0	131	85.2	0.9	83.5	86.9
41-0000	2001–2009	83.0	83.3	8.6	238	83.0	0.5	82.0	84.1
41-0000	After 2009	82.0	82.9	8.6	194	82.0	0.6	80.9	83.2
43-0000	Before 1983	82.1	82.8	9.3	508	82.0	0.4	81.3	82.9
43-0000	1984–1992	80.4	80.1	9.7	353	80.4	0.5	79.5	81.4
43-0000	1993–2000	77.6	77.3	8.3	330	77.6	0.5	76.7	78.5
43-0000	2001–2009	76.6	77.0	8.3	548	76.6	0.4	75.9	77.3
43-0000	After 2009	75.8	75.2	7.2	299	75.9	0.4	75.0	76.7
45-0000	Before 1983	91.3	91.7	8.7	734	91.3	0.3	90.6	91.9
45-0000	1984–1992	90.8	92.3	7.9	346	90.8	0.4	89.9	91.6
45-0000	1993–2000	86.6	87.2	7.2	98	86.6	0.7	85.3	88.1
45-0000	2001–2009	89.1	90.9	9.1	146	89.1	0.8	87.6	90.5
45-0000	After 2009	87.4	90.2	10.4	60	87.4	1.2	85.1	89.8
47-0000	Before 1983	87.1	88.3	7.9	51191	87.1	0.0	87.1	87.2
47-0000	1984–1992	85.7	87.0	7.6	131998	85.7	0.0	85.7	85.7
47-0000	1993–2000	83.5	84.8	8.5	108348	83.5	0.0	83.5	83.6
47-0000	2001–2009	79.4	79.5	9.8	120682	79.4	0.0	79.4	79.5
47-0000	After 2009	78.1	78.2	9.5	57008	78.1	0.0	78.0	78.2
49-0000	Before 1983	85.4	86.6	8.7	4870	85.4	0.1	85.1	85.6
49-0000	1984–1992	83.0	83.7	8.4	10139	83.0	0.1	82.8	83.1
49-0000	1993–2000	82.2	82.6	8.3	9421	82.2	0.1	82.0	82.3
49-0000	2001–2009	80.0	80.8	8.8	13841	80.0	0.1	79.8	80.1
49-0000	After 2009	77.2	77.5	8.7	6498	77.2	0.1	76.9	77.4
51-0000	Before 1983	90.7	91.5	6.8	39125	90.7	0.0	90.7	90.8
51-0000	1984–1992	88.2	89.5	8.5	28882	88.2	0.1	88.1	88.3
51-0000	1993–2000	84.0	84.6	8.7	15277	84.0	0.1	83.9	84.1
51-0000	2001–2009	82.9	83.0	7.6	40996	82.9	0.0	82.8	83.0
51-0000	After 2009	81.4	81.5	8.7	11253	81.4	0.1	81.3	81.6
53-0000	Before 1983	87.5	88.3	7.6	8546	87.5	0.1	87.3	87.7
53-0000	1984–1992	84.8	86.0	7.4	27831	84.8	0.0	84.7	84.9
53-0000	1993–2000	82.7	84.0	7.9	21074	82.7	0.1	82.6	82.8
53-0000	2001–2009	78.9	79.4	9.2	18027	78.9	0.1	78.8	79.1
53-0000	After 2009	76.4	76.2	9.2	6477	76.4	0.1	76.2	76.6
55-0000	Before 1983					78.7	4.4	70.1	87.3
55-0000	1984–1992	72.5	75.4	5.2	3	74.9	2.5	69.9	79.6
55-0000	1993–2000	83.4	83.4	4.1	2	81.6	2.5	76.8	86.5
55-0000	2001–2009	72.2	70.5	7.2	6	74.6	2.5	69.7	79.3
55-0000	After 2009	73.1	73.1		1	78.5	4.5	69.8	87.3

Collecting the terms that depend on θ_{ij}^{obs} shows that the full conditional distribution of θ_{ij}^{obs} must be proportional to

$$\left(\theta_{ij}^{\text{obs}} | \text{observed data, all other para}\right) \propto \exp\left(-\frac{\left(Y_{ij}^{\text{obs}} - \theta_{ij}^{\text{obs}}\right)^2}{2\frac{\left(s_{ij}^{\text{obs}}\right)^2}{n_{ij}^{\text{obs}}}}\right) \cdot \exp\left(-\frac{\left(\theta_{ij}^{\text{obs}} - \theta_i\right)^2}{2\sigma^2}\right).$$

After some calculations, we find that conditional on σ^2 and θ_i, θ_{ij}^{obs} must be conditionally independent of other θ_{ij}^{obs} as well as independent of the data from broad SOCs other than *ij*:

$$\theta_{ij}^{\text{obs}} \sim N\left(\mu_{ij}^{\text{obs}}, \left(\sigma_{ij}^{\text{obs}}\right)^2\right),$$

$$\text{where } \mu_{ij}^{\text{obs}} = \frac{Y_{ij}^{\text{obs}}\sigma^2 + \theta_i\frac{\left(s_{ij}^{\text{obs}}\right)^2}{n_{ij}^{\text{obs}}}}{\sigma^2 + \frac{\left(s_{ij}^{\text{obs}}\right)^2}{n_{ij}^{\text{obs}}}} \text{ and } \left(\sigma_{ij}^{\text{obs}}\right)^2 = \frac{\frac{\left(s_{ij}^{\text{obs}}\right)^2}{n_{ij}^{\text{obs}}}\sigma^2}{\left(\sigma^2 + \frac{\left(s_{ij}^{\text{obs}}\right)^2}{n_{ij}^{\text{obs}}}\right)}.$$

The conditional distribution of θ_{ik}^{mis} will be normal distribution

$$\theta_{ik}^{\text{mis}} \sim N(\theta_i, \sigma^2).$$

The conditional distribution of θ_i is also normal distribution

$$\theta_i \sim N(\mu_i, \tau_i^2),$$

where $\mu_i = \frac{\mu\sigma^2 + \sum_{j=1}^{n_i^{\text{obs}}} \theta_{ij}^{\text{obs}} \tau^2 + \sum_{k=1}^{n_i^{\text{mis}}} \theta_{ik}^{\text{mis}} \tau^2}{n_i^{\text{obs}}\tau^2 + n_i^{\text{mis}}\tau^2 + \sigma^2}$ and $\tau_i^2 = \frac{\sigma^2\tau^2}{n_i^{\text{obs}}\tau^2 + n_i^{\text{mis}}\tau^2 + \sigma^2}$.

The conditional distribution of μ is normal distribution

$$\mu \sim N\left(\frac{\sum_{i=1}^{I} \theta_i \gamma_0^2 + \mu_0\tau^2}{I\gamma_0^2 + \tau^2}, \frac{\tau^2\gamma_0^2}{I\gamma_0^2 + \tau^2}\right).$$

The conditional distribution of τ^2 will be inverse gamma distribution

$$\tau^2 \sim \text{Inv} - \text{Gamma}\left(\frac{I + \eta_0}{2}, \frac{\sum_{i=1}^{I}(\theta_i - \mu)^2 + \eta_0\tau_0^2}{2}\right).$$

The conditional distribution of σ^2 will be inverse gamma distribution

$$\sigma^2 \sim \text{Inv} - \text{Gamma}\left(\frac{\sum_{i=1}^{I} n_i^{\text{obs}} + \sum_{i=1}^{I} n_i^{\text{mis}} + \upsilon_0}{2}, \frac{\sum_{i=1}^{I}\sum_{j=1}^{n_i^{\text{obs}}}\left(\theta_{ij}^{\text{obs}} - \theta_i\right)^2 + \sum_{i=1}^{I}\sum_{k=1}^{n_i^{\text{mis}}}\left(\theta_{ik}^{\text{mis}} - \theta_i\right)^2 + \upsilon_0\sigma_0^2}{2}\right).$$

Posterior approximation proceeds by iterative sampling of each unknown quantity from its full conditional distribution. First we choose the number of iterations S to be 10,000 and decide starting values for each of these parameters. Given a current state of the unknowns $\left\{\theta_{11}^{\text{obs}(s)}, \ldots, \theta_{In_I}^{\text{obs}(s)}, \theta_{11}^{\text{mis}(s)}, \ldots, \theta_{In_I}^{\text{mis}(s)}, \theta_i^{(s)}, \mu^{(s)}, \tau^{2(s)}, \sigma^{2(s)}\right\}$, a new state is generated as follows:

1. Posterior step: sample $\theta_i^{(s+1)}, i = 1, \ldots, I$ from $\theta_i|\mu^{(s)}, \theta_{i1}^{\text{obs}(s)}, \ldots, \theta_{in_i}^{\text{obs}(s)}, \theta_{i1}^{\text{mis}(s)}, \ldots, \theta_{in_i}^{\text{mis}(s)}, \tau^{2(s)}, \sigma^{2(s)}$ based on its full conditional distribution
2. Posterior step: sample $\mu^{(s+1)}$ from $\mu|\theta_1^{(s+1)}, \ldots, \theta_I^{(s+1)}, \tau^{2(s)}$
3. Posterior step: sample $\tau^{2(s+1)}$ from $\tau^2|\theta_1^{(s+1)}, \ldots, \theta_I^{(s+1)}, \mu^{(s+1)}$
4. Posterior step: sample $\sigma^{2(s+1)}$ from $\sigma^2|\theta_{11}^{\text{obs}(s)}, \ldots, \theta_{In_I}^{\text{obs}(s)}, \theta_{11}^{\text{mis}(s)}, \ldots, \theta_{In_I}^{\text{mis}(s)}, \theta_1^{(s+1)}, \ldots, \theta_I^{(s+1)}$
5. Posterior step: sample $\theta_{ij}^{\text{obs}(s+1)}, i = 1, \ldots, I, j = 1, \ldots, n_i^{\text{obs}}$ from $\theta_{ij}^{\text{obs}}|\theta_i^{(s+1)}, \sigma^{2(s+1)}$
6. Imputation step: sample $\theta_{ij}^{\text{mis}(s+1)}, i = 1, \ldots, I, j = 1, \ldots, n_i^{\text{mis}}$ from $\theta_{ij}^{\text{mis}}|\theta_i^{(s+1)}, \sigma^{2(s+1)}$.

Appendix 2

Table 6
Figures 6 and 7

Appendix 3 – Full Time Trend Results

Table 7

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