Infection Risk based on Higher Bed Occupancy Rates

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Introduction

The SENIC data was collected as part of the SENIC (Study on the Efficacy of Nosocomial Infection Control) project conducted by Dr. Robert W. Haley and his colleages at the CDC in collaboartion with investigators from UCLA and the University of North Carolina between 1974 and 1983 (Hughes 1988). Hughes states the purpose of the study was to "evaluate nosocomial infection prevention and control programs in hospitals in the United States." Our focus aims to see the effect of higher bed occupancy rates on the risk of acquiring an infection, when controlling for geographic region, average age of patients, average length of stay, routine culturing ratio, nurse to bed ratio, and the average number of beds in the hospital.

Methods

The SENIC data consists of 113 randomly sampled United States hospitals, collected from 1975-1976. The target population was "short-term stay, general medical and surgical hospitals which were not owned by the federal or state government, had 50 or more beds, and were located in the continental United States." (Hughes 1988) Some patients were excluded due to a few factors such as: under 18 years of age, patients on burn, dialysis, opthalmology, otolaryngology, oral surgery, obstetrics, newborn, pediatric, rehabilitation, and psychiatry services, and patients hospitalized for less than 24 hours.

Table 1: Variable Descriptions

Variable	Description
risk	The average estimated probability of acquiring an infection in the hospital, multiplied by 100. The infections studied were urinary tract infections, surgical wound infectoins, pneumonias, and bacteremias. These infections account for 80% of nosocomial infections.
length	The average length of stay of patients in the hospital, in days.
age	Patients under 18 were excluded. The average age of patients in the hospital, in years.
culture	The ratio of number of cultures performed to number of patients without signs or symptoms of hospital-acquired infection, multiplied by 100.
beds	The average number of beds in a hospital during the study period.
bed_occ	This variable was calculated from the sample as the average number of patients in the hospital per day during the study period divided by the number of beds.
census	The average number of patients in the hospital per day during the study period.
region	The geographic region of the United States, coded: 1 for North East, 2 for North Central, 3 for South, 4 for West.
nurses	The average number of full-time equivalent nurses during the study period.
nurse_rat	The ratio of nurses to beds.

Statistical Analysis

Continuous variables have been summarized with either their mean and standard deviation or median and interquartile range. Cateogrical variables were summarized by frequency and percentages. These are given in Table 4. Upon inspection of the univariate and bivariate distributions, it appeared the variables length, culture, and beds were positively skewed and a log base 2 transformation removed some of the skewness and linearized the relationship with risk. The pairwise scatterplots of the continuous variables are given in Figure 1.

When assessing the collinearity, we used the correlation matrix given in Figure 1, which showed that the correlations were relatively mild except for the correlations with risk (which we want, and are expected). We then checked the Variance Inflation Factors, given in Table 5, which we found were all reasonable values. Thus we proceed.

All statistical analyses were done using R version 3.4.3.

Results

We want to investigate the effect of higher bed occupancy rates on the risk of acquiring an infection, when controlling for geographic region, average age of patients, average length of stay, routine culturing ratio, nurse to bed ratio, and the average number of beds in the hospital. From a sample of 113 privately-owned, United States hospitals performed in 1975-1976, the mean estimated nosocomial infection risk was 4.4 ± 1.3 out of 100. Characteristics of the study sample are shown in Table 4. The median average age of patients was 53 years (IQR 51-56). The average mean length of stay was 9.6 ± 1.9 days. The hospitals were sampled roughly equally across the continental United States, with slightly fewer from the South. There was a large range in the average number of beds during the study period, from 29 to 835. The average mean bed occupancy rate over the study period was 0.7.

Predictors of Infection Risk

Table 6 shows the results from regressing risk on the other variables, both adjusted and unadjusted. A list of interpretations for the marginal and partial coefficients are as follows in Tables 2 and 3:

Table 2: Marginal Coefficient Interpretations

Variable	Coefficient	Interpretation
length	2.87	A doubling in average length of stay is associated with a mean increase of 2.87 points in infection risk.
age	0.0003	For each additional year in average age, infection risk rises by 0.0003 points on average.
culture	0.85	A doubling in the culturing ratio is associated with a mean increase of 0.85 points in infection risk.
beds	0.57	A doubling in the average number of beds is associated with a mean increase of 0.57 points in infection risk.
bed_occ	3.35	A 0.01 increase in the bed occupancy rate is associated with a mean increase of 0.0335 points in infection risk.
nurse_rat	2.27	For each additional nurse per bed, infection risk rises by 2.27 on average.
region	4.86	In the North East region, the average infection risk is 4.86.
neregion	-0.47	In the North Central region, the infection risk is on average 0.47 points lower than the North East region.
wregion	-0.48	In the Western region, the infection risk is on average 0.48 points lower than the North East region.
sregion	-0.93	In the Southern region, the infection risk is on average 0.93 points lower than the North East region.

Table 3: Partial Coefficient Interpretations

Variable	Coefficient	Interpretation
length	2.01	A doubling in average length of stay is associated with a mean increase of 2.01 points in infection risk, all else equal.
age	0.03	For each additional year in average age, infection risk rises by 0.03 points on average, all else equal.
culture	0.65	A doubling in the culturing ratio is associated with a mean increase of 0.65 points in infection risk, all else equal.
beds	0.23	A doubling in the average number of beds is associated with a mean increase of 0.23 points in infection risk, all else equal.
bed_occ	0.004	A 0.01 increase in the bed occupancy rate is associated with a mean increase of 0.004 points in infection risk, all else equal.
nurse_rat	0.68	For each additional nurse per bed, infection risk rises by 0.68 on average, all else equal.
region	-8.91	In the North East region, the average infection risk is -8.91 when all of the other predictors are 0. This is not meaningful.
neregion	0.41	In the North Central region, the infection risk is on average 0.41 points higher than the North East region.
wregion	1.09	In the Western region, the infection risk is on average 1.09 points higher than the North East region.
sregion	0.28	In the Southern region, the infection risk is on average 0.28 points higher than the North East region.

Conclusion

When we performed the simple linear regression of infection risk on the bed occupancy rate, we found that higher occupancies were associated with an increase in infection risk, p = 0.002. However, once we controlled for geographic region, average age of patients, average length of stay, routine culturing ratio, nurse to bed ratio, and the average number of beds in the hospital we found that bed occupancy rate was still positive but no longer statistically significant at the $\alpha = 0.05$ level, p = 0.651. Therefore the data does not support the hypothesis.

Limitations

Our model used the 113 hospitals, without removing outliers and those with high leverage. Looking at the bivariate distributions in Figure 1 we see there are a few values of the log base 2 of length that have high influence. Also, our model does not deal with any possible interaction between variables. This could be a source of further study.

References

1. Hughes, James M. "Study on the Efficacy of Nosocomial Infection Control (SENIC Project): Results and Implications for the Future." Chemotherapy, vol. 34, no. 6, 1988, pp. 553–561., doi:10.1159/000238624.

Tables and Figures

Table 4: Sample Characteristics

Characteristic	Hospitals (n = 113)
Estimated Nosocomial Infection Risk, mean $\pm$ SD	4.4 $\pm$ 1.3
Average Age of Patients, years, median (IQR)	53 (51-56)
Average Length of Stay, days, mean $\pm$ SD	9.6 $\pm$ 1.9
Routine Culturing Ratio, mean $\pm$ SD	15.8 $\pm$ 10.2
Number of Beds, mean $\pm$ SD	252 $\pm$ 193
Average Bed Occupancy Rate, mean $\pm$ SD	0.7 $\pm$ 0.1
Average Number of Full-Time Nurses, mean $\pm$ SD	173 $\pm$ 139
Region	
North East	28 (24.8)
North Central	32 (28.3)
West	37 (32.7)
South	16 (14.2)

Table 5: Variance Inflation Factors

Variable	$\sqrt{VIF}$
log2length	1.47
age	1.14
log2culture	1.25
log2beds	1.20
bed occ	1.26
nurse rat	1.18
ncregion	1.36
wregion	1.41
sregion	1.44

Table 6: Regression Coefficients

	Unadjusted		Adjusted	
Variable	β (95% CI)	p	β (95% CI)	p
Length of Stay, per two-fold increase	2.87 (2.05, 3.69)	<0.001	2.01 (1.09, 2.93)	<0.001
Age, years	0.0003 (-0.06, 0.06)	0.99	0.03 (-0.1, 0.07)	0.181
Culturing Ratio, per two-fold increase	0.85 (0.65, 1.04)	<0.001	0.65 (0.45, 0.85)	<0.001
Ave No of Beds, per two-fold increase	0.57 (0.36, 0.78)	<0.001	0.23 (0.05, 0.41)	0.013
Bed Occupancy Rate	3.35 (1.25, 5.45)	0.002	0.40 (-1.35, 2.15)	0.651
Nurse Ratio	2.27 (1.10, 3.43)	<0.001	0.68 (-0.25, 1.61)	0.148
Region				
North East - Reference group	4.86 (4.37, 5.35)	<0.001	-8.91 (-12.08, -5.74)	<0.001
North Central	-0.47 (-1.14, 0.21)	0.172	0.41 (-0.07, 0.89)	0.093
West	-0.48 (-1.29, 0.33)	0.246	1.09 (0.45, 1.73)	0.001
South	-0.93 (-1.58, -0.28)	0.005	0.28 (-0.20, 0.77)	0.253

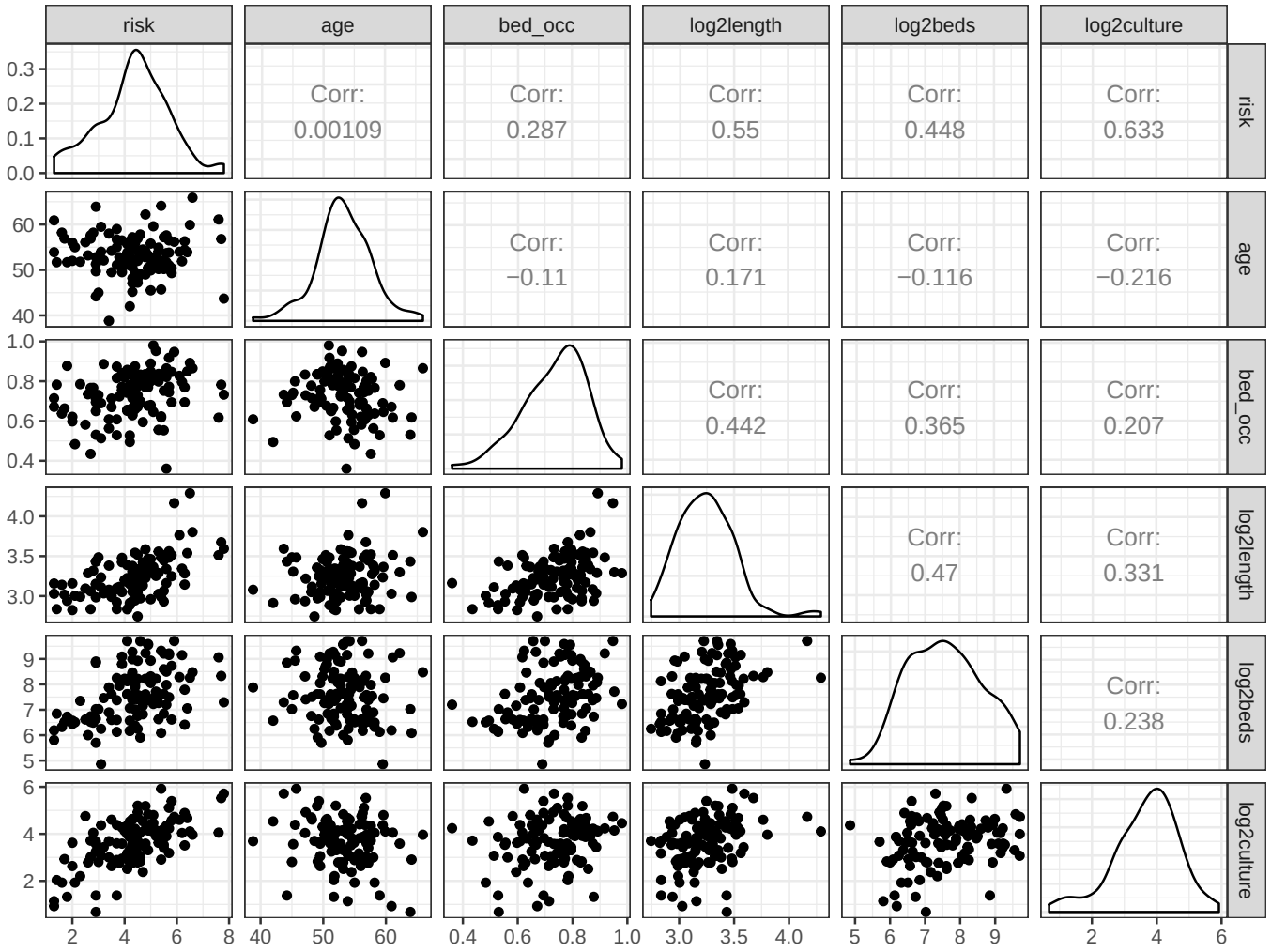

Figure 1: Bivariate Distributions of Continuous Variables