ONLINE APPENDIX

Does Hospital Crowding Matter?

Evidence from Trauma and Orthopedics in England

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March 13, 2021

1 Appendix A: Additional charts and tables

Table A1: Descriptive statistics for elective and emergency inpatients

	Elective	Emergency
Age	55.5	58.3
Male, %	46.8	48.3
White, %	84.9	85.8
Diagnosis count	2.9	4.5
Co-morbidity index	1.2	2.9
Past ED visits	0.2	1.4
Elective wait time, days	86.0	0.0
Daycase operation, %	36.2	9.6
Delayed treatment, %	15.0	67.9
Number of procedures	1.2	1.1
Length of stay, days	2.0	8.5
Transfers out, %	0.7	7.0
Home discharge, %	98.5	84.5
7-day unplanned readmission, %	1.3	5.5
30-day in-hospital mortality, %	0.1	3.0

Notes: (1) 'Co-morbidity index' is defined according to the Charlson index, on a scale between 0 and 50; (2) 'Past ED visit' is a count over the 12 months prior to the index admission; (3) 'Daycase operation' is equal to 1 if a patient receives a procedure that, for that hospital and year, results in no overnight stay for the median patient, and equal to 0 otherwise; (4) 'Delayed treatment' is equal to 1 if a patient receives their primary procedure the day after admission, and equal to 0 otherwise.

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Table A2: Top 10 diagnoses for elective and emergency patients

Diagnosis	Most common procedure	N	Mean age	Male, %	Readmission, %	Mortality, %
Elective patients						
Gonarthrosis, unspecified	Total prosthetic replacement of knee joint	266,094	66	44	2.2	0.1
Coxarthrosis, unspecified	Total prosthetic replacement of hip joint	182,403	68	40	2.3	0.1
Carpal tunnel syndrome	Carpal tunnel release	160,924	59	33	0.4	0.0
Removal of internal fixation device	Removal of internal fixation from bone	77,666	43	56	0.7	0.0
Impingement syndrome of shoulder	Subacromial decompression	66,979	55	49	0.6	0.0
Hallux valgus (acquired)	Soft tissue correction of hallux valgus	63,869	55	11	0.6	0.0
Derangement of meniscus (medial)	Endoscopic resection of semilunar cartilage	62,120	49	65	0.5	0.0
Primary gonarthrosis, bilateral	Total prosthetic replacement of knee joint	56,544	66	43	2.1	0.1
Intervertebral disc disorders	Therapeutic sacral epidural injection	49,957	50	49	1.1	0.0
Derangement of meniscus (posterior)	Endoscopic resection of semilunar cartilage	45,303	50	67	0.5	0.0
Emergency patients						
Fracture of neck of femur	Prosthetic replacement of head of femur	200,306	80	27	5.4	9.1
Fracture of lower end of radius	Open reduction of fracture and fixation	74,594	56	30	3.9	0.2
Pertrochanteric fracture	Closed reduction of fracture and fixation	70,518	81	28	5.9	9.3
Fractures of other parts of lower leg	Open reduction of fracture and fixation	67,383	52	39	4.0	0.4
Mechanical complication of prosthesis	Closed reduction of dislocated prosthetic hip	41,297	75	31	8.1	1.8
Fracture of upper end of humerus	Open reduction of fracture and fixation	28,085	66	33	5.7	1.6
Cellulitis of other parts of limb	Intravenous infusion of therapeutic substance	25,565	53	66	4.2	0.4
Fracture of lateral malleolus	Open reduction of fracture and fixation	23,560	47	54	2.9	0.2
Fracture of upper end of tibia	Open reduction of fracture and fixation	22,347	53	47	5.0	0.8
Fracture of lower end of tibia	Open reduction of fracture and fixation	21,878	46	60	4.7	0.7

Notes: (1) Diagnoses are individual ICD-10 codes; (2) Procedures are individual OPCS codes; (3) Diagnosis and procedure descriptions abbreviated for presentation.

Table A3: OLS estimates of the effect of emergency admissions on health outcomes by different measurement windows

	All patients		Elective		Emergency	
	ACE	SE	ACE	SE	ACE	SE
Panel A: Admission cohorts						
7-day unplanned readmission	0.009**	(0.004)	0.003	(0.003)	0.016**	(0.008)
15-day unplanned readmission	0.010**	(0.004)	0.002	(0.004)	0.023**	(0.009)
30-day unplanned readmission	0.008	(0.005)	0.000	(0.005)	0.022*	(0.012)
7-day in-hospital mortality	0.002	(0.002)	0.001	(0.001)	0.005	(0.005)
15-day in-hospital mortality	0.002	(0.002)	0.001	(0.001)	0.003	(0.006)
30-day in-hospital mortality	0.002	(0.002)	0.001	(0.001)	0.003	(0.006)
Panel B: Discharge cohorts						
7-day unplanned readmission	0.048***	(0.007)	0.010***	(0.003)	0.104***	(0.016)
15-day unplanned readmission	0.049***	(0.007)	0.010**	(0.004)	0.106***	(0.016)
30-day unplanned readmission	0.044***	(0.006)	0.009**	(0.005)	0.095***	(0.016)
7-day in-hospital mortality	−0.002	(0.002)	0.001	(0.001)	−0.005	(0.005)
15-day in-hospital mortality	−0.001	(0.002)	0.001	(0.001)	−0.002	(0.005)
30-day in-hospital mortality	−0.001	(0.002)	0.001	(0.001)	−0.003	(0.006)

Notes: (1) ACE is the average crowding effect; (2) All specifications include a fully interacted set of diagnosis, age category, and emergency status fixed effects, and hospital-specific year, weekly-seasonal, and day-of-week fixed effects; (3) N = 4,279,800 for all patients, N = 2,765,890 for elective patients, and N = 1,513,910 for emergency patients; (4) Standard errors clustered at the hospital-level (177 clusters); (5) ***/**/* indicates statistical significance at the 1/5/10% level.

Table A4: OLS estimates of the effect of emergency admissions on health outcomes and treatment decisions with different sets of control variables

	All patients						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Admission cohorts							
7-day unplanned readmission	0.009**	0.009**	0.009**	0.009**	0.009**	0.009***	0.009**
30-day in-hospital mortality	0.002	0.002	0.002	0.003	0.003	0.003	0.003
Daycase operation, %	0.022**	0.022**	0.022**	0.020**	0.020**	0.020**	0.023**
Delayed operation, %	0.188***	0.188***	0.187***	0.191***	0.191***	0.191***	0.190***
Number of procedures	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***
Panel B: Discharge cohorts							
7-day unplanned readmission	0.048***	0.048***	0.048***	0.049***	0.049***	0.050***	0.052***
30-day in-hospital mortality	−0.001	−0.001	−0.001	0.002	0.003	0.003	0.003
Length of stay, days	−0.030***	−0.030***	−0.030***	−0.025***	−0.025***	−0.025***	−0.026***
Transfers out, %	0.000	0.000	0.000	0.001	0.001	0.001	0.001
Discharges to home, %	0.003	0.003	0.003	−0.002	−0.002	−0.003	−0.002
Control variables (both panels)							
Baseline fixed effects	✓	✓	✓	✓	✓	✓	✓
Gender fixed effects		✓	✓	✓	✓	✓	✓
Ethnicity fixed effects			✓	✓	✓	✓	✓
Diagnosis count				✓	✓	✓	✓
Co-morbidity index					✓	✓	✓
Past ED admits						✓	✓
Wait time, days							✓

Notes: (1) Estimates are the average crowding effect (ACE); (2) Wait time is equal to the number of days waiting prior to surgery for elective patients and is set equal to zero for all emergency patients; (3) N = 4,279,800; (4) Standard errors clustered at the hospital-level (177 clusters); (5) ***/**/* indicates statistical significance at the 1/5/10% level.

Table A5: OLS estimates of the effect of emergency admissions on readmission specialties (ordered by frequency of specialty)

	ACE	SE	N
Panel A: Admission cohorts			
Trauma and orthopedics	0.0097***	(0.0023)	
General medicine	0.0001	(0.0018)	
Geriatric medicine	0.0003	(0.0011)	
Accident and emergency	−0.0006	(0.0009)	
Plastic surgery	0.0000	(0.0010)	
General surgery	0.0009	(0.0006)	
Neurosurgery	−0.0003	(0.0006)	
Rehabiliation service	−0.0003	(0.0005)	
Cardiology	0.0003	(0.0004)	
Respiratory medicine	0.0001	(0.0004)	
Panel B: Discharge cohorts			
Trauma and orthopedics	0.0444***	(0.0059)	
General medicine	0.0026	(0.0016)	
Geriatric medicine	−0.0012	(0.0010)	
Accident and emergency	0.0002	(0.0008)	
Plastic surgery	0.0011	(0.0012)	
General surgery	0.0002	(0.0006)	
Neurosurgery	0.0023***	(0.0006)	
Rehabiliation service	−0.0003	(0.0004)	
Cardiology	0.0000	(0.0004)	
Respiratory medicine	0.0001	(0.0004)	

Notes: (1) ACE is the average crowding effect; (2) Dependent variables are indicators for whether a readmission event was associated with a particular medical specialty, shown for the top 10 specialties; (3) All specifications include a fully interacted set of diagnosis, age category, and emergency status fixed effects, and hospital-specific year, weekly-seasonal, and day-of-week fixed effects; (4) Standard errors clustered at the hospital-level (177 clusters); (5) ***/**/* indicates statistical significance at the 1/5/10% level.

Table A6: Descriptive statistics for the hospital-level heterogeneity variables

Label	Hospital characteristic	Mean	St. dev.
1	T&O senior physicians	3.93	1.62
2	T&O inpatient beds	35.38	20.13
3	Hospital-wide inpatient beds	535.20	206.29
4	Mean daily emergency admissions	3.76	1.69
5	Predicted mortality, emergencies	3.05	1.03
6	RTT target performance	77.82	8.99
7	Teaching hospital	0.16	0.37
8	7-day readmission, ACE	0.07	0.22
9	Length of stay, ACE	−0.03	0.08
10	Senior physician, ACE	0.67	1.41
11	Predicted readmission, ACE	−0.08	0.93

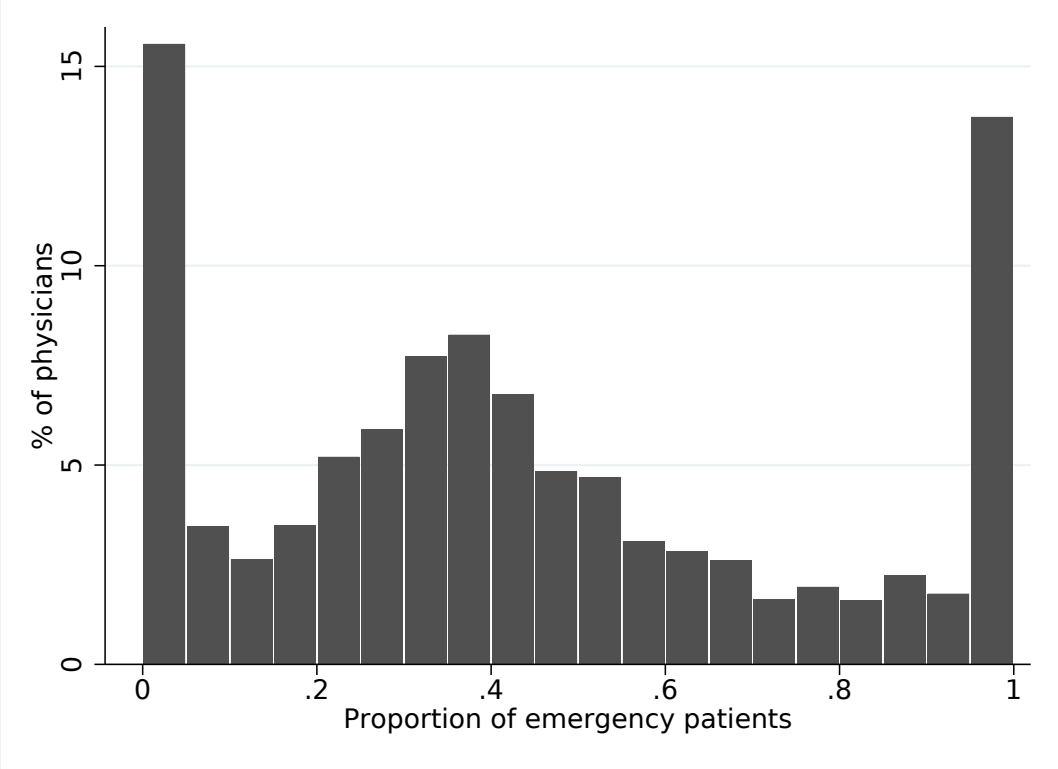
Notes: (1) Variable labels used in the correlation matrix shown in Table A7.

Table A7: Correlation matrix for the hospital-level heterogeneity variables

	Variable label (see Table A6)										
	1	2	3	4	5	6	7	8	9	10	11
1	1.00										
2	0.53	1.00									
3	0.47	0.55	1.00								
4	0.46	0.66	0.60	1.00							
5	−0.25	−0.07	−0.13	−0.10	1.00						
6	−0.04	0.02	0.06	0.09	−0.10	1.00					
7	0.09	0.16	0.35	0.16	−0.14	0.00	1.00				
8	−0.14	−0.13	−0.09	−0.06	0.53	−0.17	−0.05	1.00			
9	0.23	0.17	0.14	0.07	−0.49	0.17	0.05	−0.69	1.00		
10	0.44	0.15	0.15	−0.07	−0.10	−0.06	0.00	−0.07	0.17	1.00	
11	0.05	0.12	0.16	0.15	−0.23	−0.01	0.05	0.06	0.07	−0.02	1.00

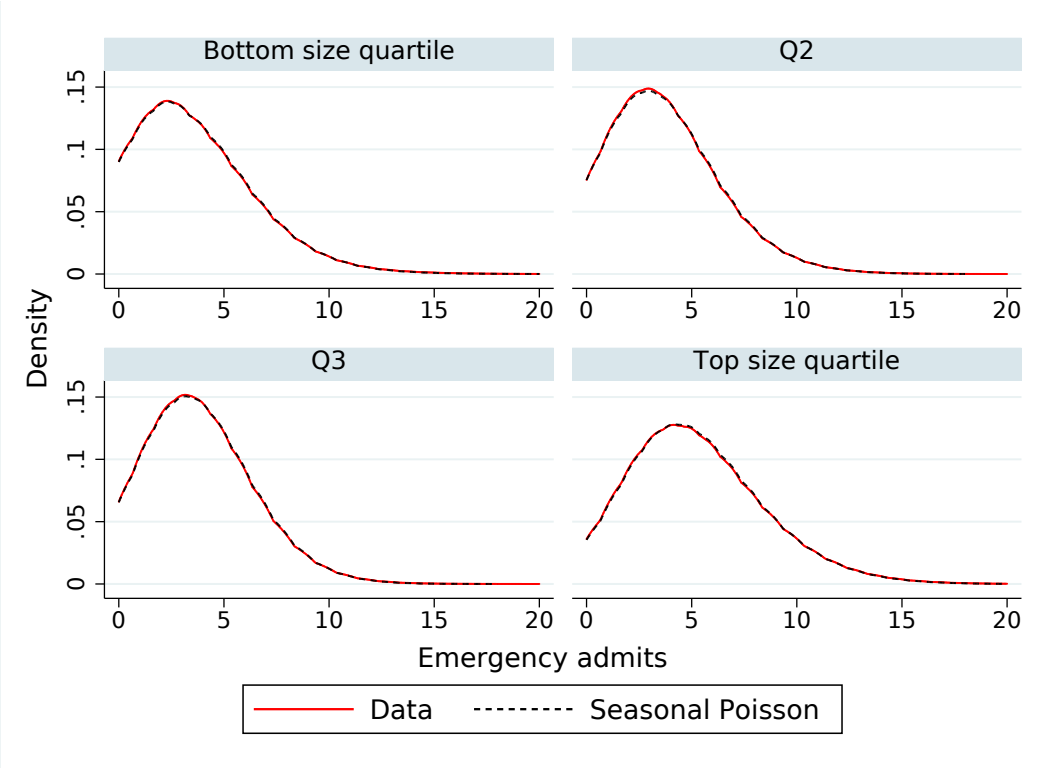
Notes: (1) Variable labels in the first column and second row given in Table A6.

Figure A1: Proportion of inpatients that arrive through the ED by each senior physician



Notes: (1) Each patient under the care of a senior physician is classified as either receiving emergency or elective care, and physician-level means for emergency care are plotted in the histogram.

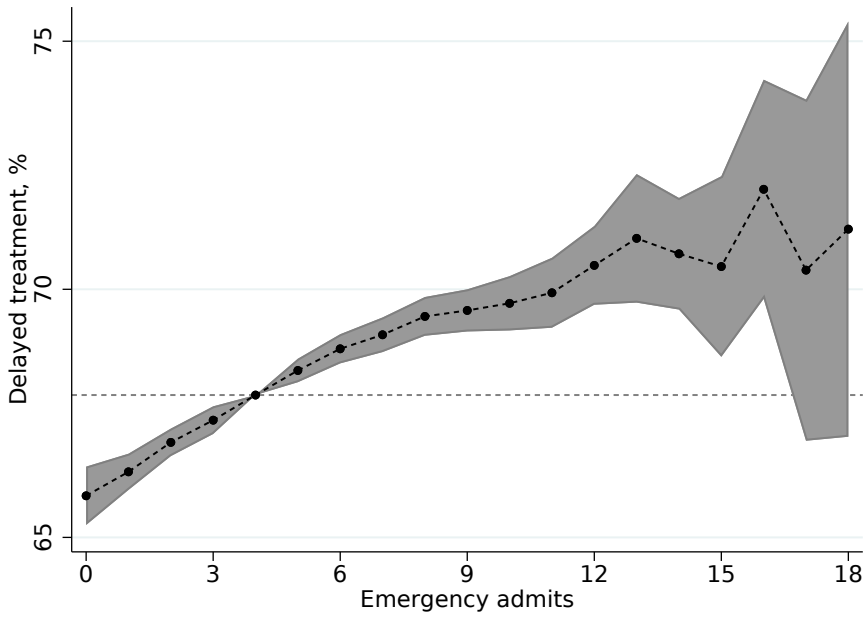
Figure A2: Poisson property of daily emergency admissions



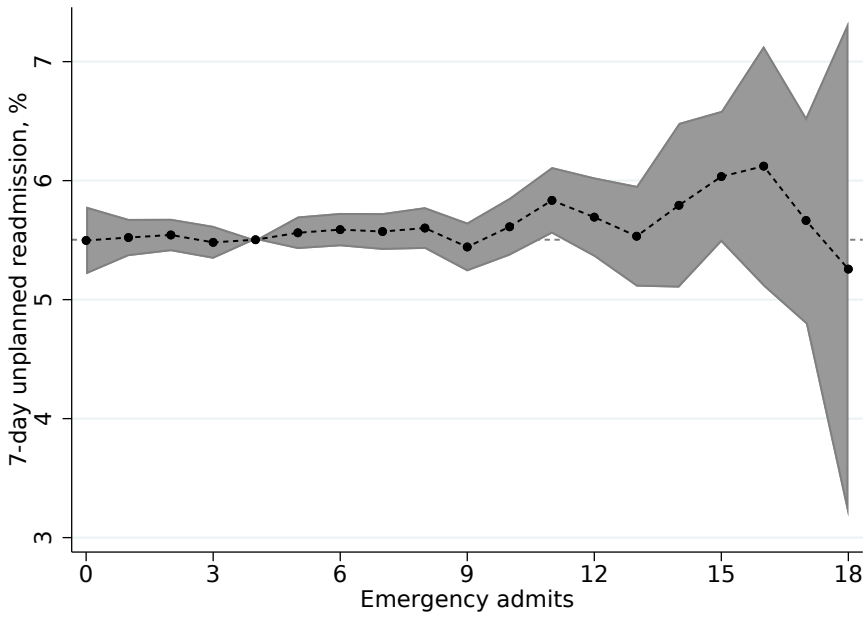
Notes: (1) This figure shows that the empirical distribution of emergency admissions closely matches the theoretical Poisson distribution and, in particular, that the Poisson property of the distribution's mean being equal to its variance also holds; (2) Size quartiles are defined by the mean daily emergency admissions of each hospital; (3) Poisson data simulated for each hospital with a mean equal to expected emergency admissions, which is defined by a regression of emergency admissions on hospital-specific year, week-seasonal, and day-of-the-week fixed effects.

Figure A3: Non-parametric estimates of the effect of emergency admissions on 7-day unplanned readmission and delayed treatment for emergency admission cohorts

(a) Delayed treatment (emergency admission cohorts)

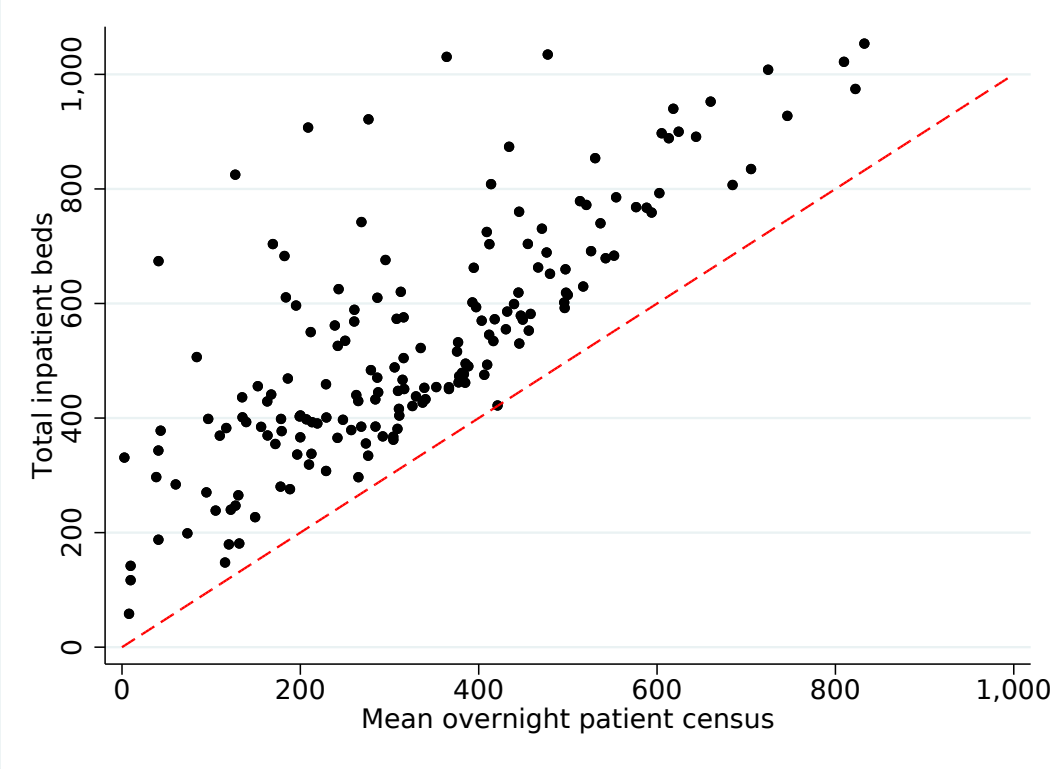


(b) 7-day unplanned readmission (emergency admission cohorts)



Notes: (1) Base category of 4 emergency admissions normalized to the unconditional mean of emergency admissions; (2) Estimates for values of emergency admissions above 18 omitted from the figure and are mostly statistically insignificant; (3) Standard errors clustered at the hospital-level (177 clusters) with 95% confidence intervals shown in the shaded region.

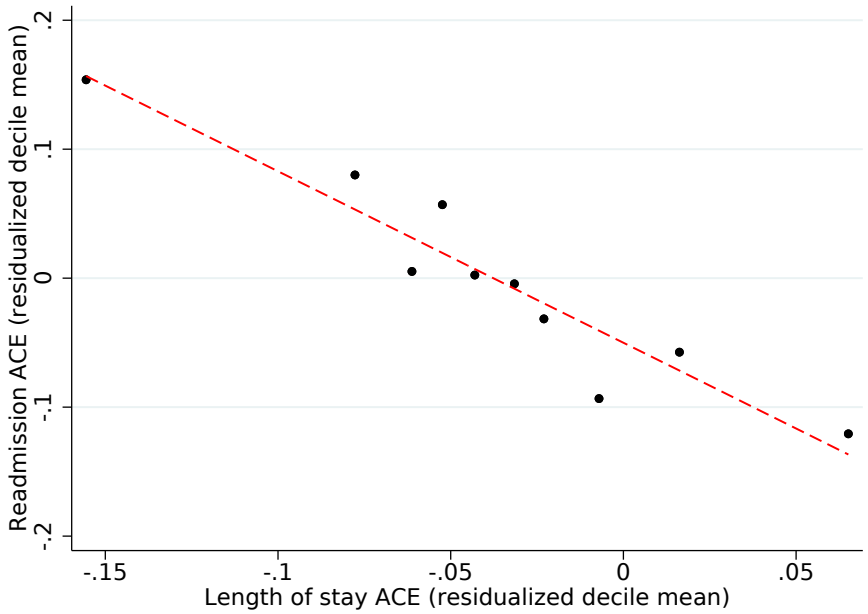
Figure A4: Scatter plot of hospital inpatient beds versus overnight patient census



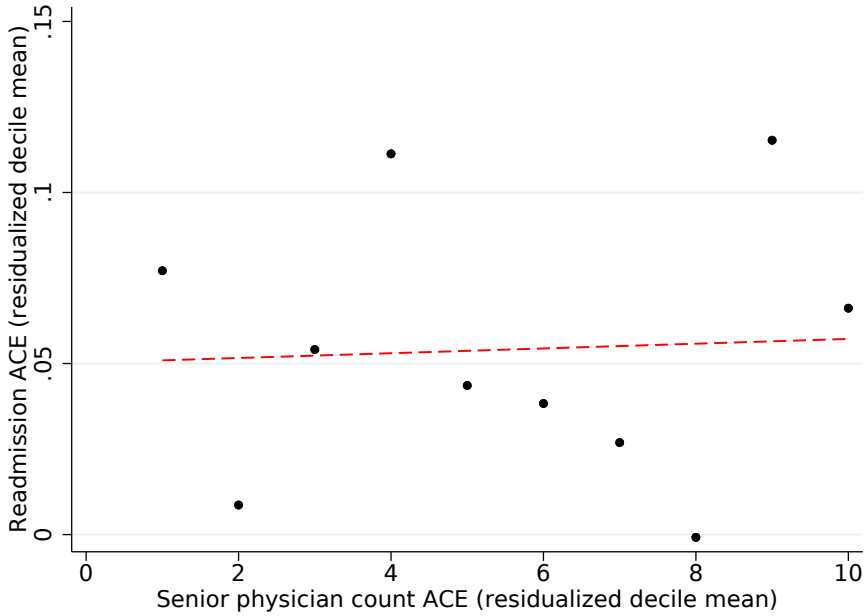
Notes: (1) The hospital inpatient beds measure is an annual average over the period 2007-2013; (2) The overnight patient census is measured at midnight each day, recording the total number of patients in the hospital, and it is then averaged over the period 2007-2013; (3) The red dashed line is the 45-degree line.

Figure A5: Scatter plots of the hospital-level readmission ACEs against the length of stay and physician response ACEs after controlling for hospital characteristics

(a) Length of stay



(b) Physician response



Notes: (1) ACE is the average crowding effect; (2) The ACE on the x-axis is computed for each hospital, residualized using the hospital characteristics, and then I report the mean residual in each decile; (3) The ACE on the y-axis is computed for each hospital, residualized using the hospital characteristics, and then I report the mean residual for each decile of the x-axis; (4) For each residualized decile mean I add the across-hospital ACE to rescale the estimates; (5) Red dashed lines are regression estimates of the slope of each relationship.

2 Appendix B: Serial correlation in emergency admissions

To study the time-series properties of emergency admissions, I decompose the emergency admissions using the following specification

$$q_{hs} = \theta_{hy} + \eta_{hw} + \kappa_{hd} + z_{hs}, \tag{1}$$

where q_{hs} is the number of emergency admissions at hospital h on day s, θ_{hy}, η_{hw} and κ_{hd} are hospital-specific year, weekly-seasonal, and day-of-week fixed effects (consistent with the baseline specification) and z_{hs} is an error term. I refer to predicted values from this regression as 'expected admissions' and the residuals as 'emergency shocks'. The variation in z_{hs} is equivalent to the variation in q_{hs} after partialing out the hospital-specific fixed effects. The adjusted R^2 statistic from estimating Equation (1) is 0.44 indicating that the hospital-specific seasonality explains just under half of the variation in emergency admissions. Across the full sample, emergency shocks have a mean of zero and a standard deviation of 1.99 (approximately 2 patients).

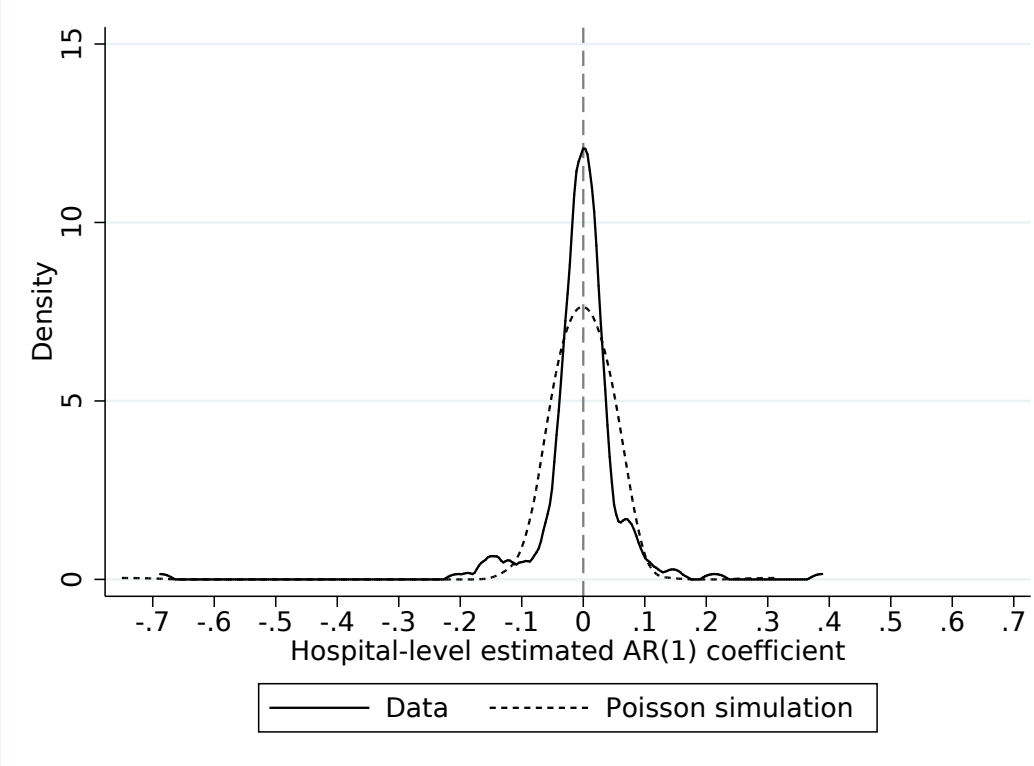
To evaluate the first-order serial correlation in the shocks, for each hospital I regress the emergency shocks on its lag, and then obtain the distribution of AR(1) coefficients across hospitals. Figure B1 presents this distribution. The distribution is centered at zero and is symmetric, consistent with the shocks being pseudo-random at each hospital and estimation error creating the variation around zero. Looking at the first-order serial correlation tests for individual hospitals shows that in 88% of cases I cannot reject the hypothesis of no serial correlation. Similar results are found if the emergency shocks are squared and the analysis repeated.

Figure B1 also shows the distribution of estimated AR(1) coefficients from simulated data, where each hospital has Poisson distributed admissions with a parameter equal to the hospital-specific mean of emergency admissions. In the simulated data there is zero serial correlation by definition. The distribution using simulated data is similar to that using the observed data, although the observed data has a higher standard deviation on account of a few outlying coefficients. If these hospitals with outlying coefficients are excluded from the baseline analysis then the results are qualitatively unchanged.

Overall these results indicate that, for the large majority of hospitals, the emergency shock today is independent of the emergency shock yesterday or tomorrow. With random shocks, the

number and type of patients at a hospital when a shock occurs should be uncorrelated with the shock size. Figure B2 illustrates this graphically. It shows binned scatter plots of the shock distribution against the number of patients (patient census) in Figure B2a and against the type of patients (predicted 30-day mortality) in Figure B2b. Both figures show that there is no discernible relationship between the shocks and the volume or type of patients at the hospital when the shock occurs.

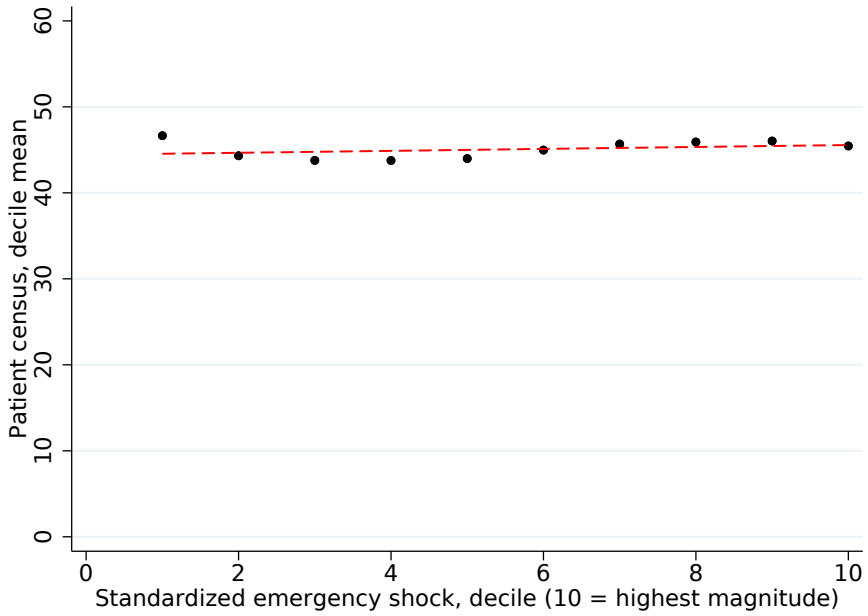
Figure B1: Hospital-level tests of first-order serial correlation



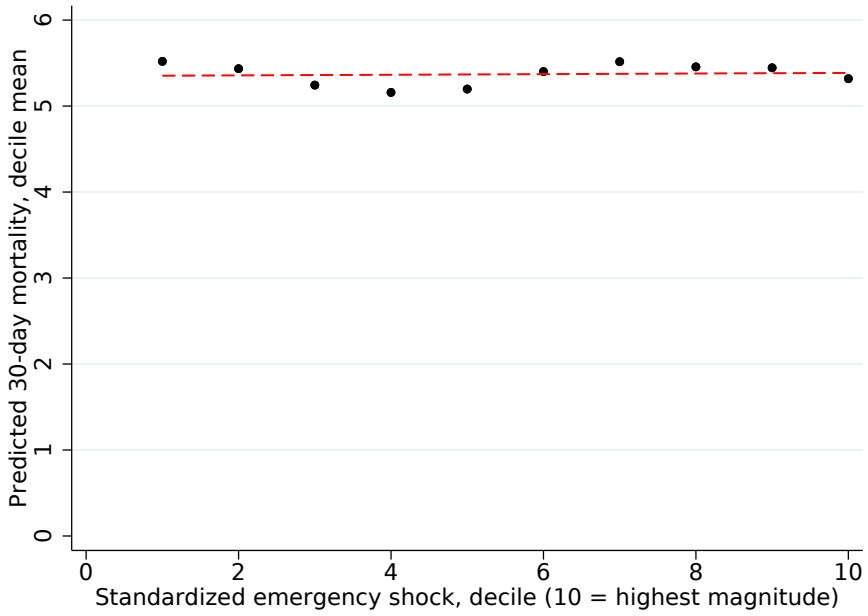
Notes: (1) Figure shows the density of estimated AR(1) coefficients from regressions of emergency shocks on their lag for each hospital separately using the actual data and simulated data based on a Poisson distribution; (2) Emergency shocks in the data are defined as residuals from a regression of daily emergency admissions on hospital-specific year, weekly seasonal, and day-of-the-week fixed effects; (3) In the simulation each hospital has Poisson distributed admissions with a parameter equal to the hospital-specific mean of emergency admissions.

Figure B2: Binned scatter plots of standardized emergency shocks versus the census and predicted mortality of pre-existing patients

(a) Patient census



(b) 30-day predicted mortality



Notes: (1) Standardized emergency shocks are defined as the residuals from Equation (1) normalized by the hospital-specific standard deviation of that variable; (2) Patient census is defined as the mean count of patients at each hospital at midnight on the day prior to the shock; (3) Predicted 30-day mortality is defined as the mean prediction for patients at each hospital at midnight on the day prior to the shock; (4) Red dashed lines are regression estimates of the slope of each relationship.