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2 **Supplementary Information for**
3 **Nursing home staff networks and COVID-19**

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7 **This PDF file includes:**

8 Supplementary text

9 Fig. S1

10 Tables S1 to S6

11 **Supporting Information Text**

12 In this Supplement, we provide tables with network summary statistics by state, as well as full results from
13 our main regression specification and three robustness checks. In Table S1, we report mean values and
14 standard deviations of our four network measures, for all 48 contiguous states and the District of Columbia.

15 Next, we show all coefficient estimates for our main analysis in Table S2. Table S3 shows results for our
16 main network measures, *Degree* and *Strength*, by individual state, for the 22 states with detailed COVID-19
17 case counts prior to the mandated reporting by CMS in late-May.

18 In Table S4, we repeat our main analysis replacing the inverse hyperbolic sine of the number of cases
19 in the nursing home with a binary variable that equals 1 if the nursing home has reported COVID cases
20 among its residents. Here, for example, the results in column (1) suggest that, when 10 additional nursing
21 home connections are added, the probability that a home has cases increases by 6.6 percentage points. In
22 the overall data, 42 percent of homes have cases. The network measures are all statistically significant in
23 this alternative specification. In Table S5 we repeat our main analysis replacing the state fixed effects with
24 county fixed effects. This allows a smaller number of units within which variation can be measured. The
25 urban variable, which is measured at the county-level, is omitted. Results are qualitatively similar to our
26 state fixed effects data though, as expected, significance levels diminish somewhat.

27 As a final robustness check, we repeat our main analysis in Table S6 using data from CMS rather than
28 data from the individual states. This allows us to examine the 48 continental United States plus the District
29 of Columbia, but these data are subject to the reporting limitation that homes were not required to add
30 cases prior to May into their cumulative case totals. The CMS data reports cases in 48 percent of nursing
31 homes by week-ending May 31, 2020 but reports overall fewer cases than the individual state data. This
32 is expected since the CMS data did not require homes to report cases in the cumulative total that had
33 resolved before May 2020. In this robustness specification, point estimates for the network variables are
34 slightly smaller than in our base specifications but qualitatively extremely similar.

Table S1. State-level network summary statistics, mean and standard deviation

State	Resident COVID Cases per Nursing Home				Degree		Strength		Weighted Avg. Neighbor Degree		Eigenvector Centrality	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
	AL	10.0	19.9	5.8	4.8	8.3	8.5	7.9	4.1	0.15	0.21	
AR	4.5	16.1	3.4	3.2	4.5	5.0	4.6	3.3	0.09	0.18		
AZ	6.1	14.2	4.9	5.0	6.4	7.6	7.1	5.2	0.14	0.21		
CA	11.0	26.3	6.0	8.2	7.3	13.0	9.5	8.5	0.04	0.13		
CO	8.0	16.9	3.8	4.4	4.5	5.2	5.5	4.7	0.11	0.18		
CT	36.5	54.6	6.6	6.7	7.3	7.6	9.6	6.0	0.13	0.21		
DC	26.8	39.7	6.3	2.4	9.6	4.7	7.4	0.9	0.65	0.23		
DE	23.8	37.8	3.0	2.5	3.5	3.4	4.4	2.6	0.27	0.26		
FL	5.6	15.4	11.4	8.9	14.4	12.1	15.4	6.7	0.09	0.15		
GA	17.9	42.5	8.6	8.6	12.4	17.7	11.7	8.0	0.10	0.18		
IA	4.1	11.2	3.7	3.6	4.6	5.2	5.4	3.8	0.10	0.19		
ID	4.6	30.7	1.5	1.7	2.0	2.3	2.0	1.9	0.15	0.26		
IL	15.8	32.5	9.3	11.6	10.6	13.6	13.9	11.6	0.07	0.18		
IN	6.8	20.5	7.4	8.2	9.2	11.5	11.4	8.0	0.08	0.15		
KS	1.8	7.1	5.3	5.9	6.6	7.9	7.8	5.9	0.08	0.19		
KY	5.2	17.2	5.1	5.3	7.2	11.6	7.4	5.4	0.13	0.20		
LA	13.8	24.1	5.7	5.6	7.3	7.4	7.8	5.1	0.10	0.23		
MA	33.4	48.2	6.5	6.4	7.2	7.4	9.8	5.9	0.10	0.18		
MD	20.3	36.2	12.9	13.6	15.3	17.5	19.3	11.4	0.19	0.28		
ME	3.7	12.1	1.3	1.7	1.6	2.3	1.6	1.9	0.09	0.24		
MI	11.9	24.5	4.5	4.7	5.4	6.0	6.2	4.7	0.05	0.17		
MN	6.6	16.5	3.6	4.2	4.2	5.1	5.6	5.2	0.09	0.18		
MO	4.7	16.8	6.0	7.0	7.7	10.5	9.0	7.0	0.07	0.16		
MS	7.9	19.6	4.1	4.2	5.5	6.5	6.2	4.3	0.10	0.24		
MT	1.1	4.5	1.5	2.0	1.9	2.7	1.9	2.2	0.13	0.24		
NC	7.0	20.4	6.8	6.7	8.6	11.0	9.7	5.9	0.08	0.18		
ND	3.3	8.2	1.9	3.1	3.6	7.1	6.7	8.1	0.11	0.15		
NE	4.1	13.2	2.4	2.5	2.7	3.0	3.4	2.7	0.10	0.17		
NH	17.4	46.7	2.8	3.2	3.1	3.9	4.1	3.6	0.15	0.31		
NJ	33.9	49.8	10.4	8.2	12.6	11.0	15.0	6.0	0.23	0.20		
NM	3.2	11.7	3.8	4.1	5.4	7.8	5.0	4.3	0.17	0.23		
NV	17.7	34.9	3.3	3.1	4.0	4.4	4.2	3.1	0.29	0.35		
NY	24.3	46.3	7.8	9.4	10.6	14.7	12.6	9.6	0.07	0.20		
OH	5.6	15.9	8.8	8.0	10.9	11.3	13.3	7.6	0.05	0.10		
OK	2.2	8.2	5.6	6.5	6.9	8.6	7.8	6.4	0.09	0.19		
OR	2.8	7.2	3.0	3.4	3.4	3.9	4.2	3.6	0.10	0.21		
PA	19.1	39.2	7.2	7.9	9.8	15.6	10.6	7.8	0.07	0.16		
RI	22.5	38.8	4.6	3.8	5.0	4.4	6.7	3.5	0.23	0.23		
SC	9.7	23.7	5.1	4.4	7.1	6.8	6.7	4.0	0.10	0.20		
SD	2.1	6.2	1.0	1.2	1.2	1.8	1.4	1.6	0.05	0.18		
TN	2.9	8.4	5.7	4.9	7.9	8.1	8.6	4.7	0.11	0.17		
TX	3.8	18.8	9.2	10.4	13.4	50.2	14.3	10.6	0.04	0.12		
UT	4.4	25.8	2.8	3.3	3.8	5.0	4.2	3.6	0.13	0.22		
VA	9.3	23.4	6.8	7.4	8.3	9.3	9.8	6.8	0.11	0.22		
VT	9.2	19.9	0.5	1.1	0.6	1.3	0.6	1.2	0.12	0.31		
WA	6.3	18.6	4.3	5.8	4.7	6.4	6.0	6.0	0.11	0.27		
WI	4.0	10.9	3.2	4.4	4.1	6.8	4.8	5.1	0.06	0.19		
WV	3.3	10.8	3.6	3.7	5.3	8.0	5.8	4.5	0.14	0.24		
WY	1.1	3.1	0.5	0.9	0.8	1.8	0.5	1.0	0.11	0.29		

COVID-19 cases include confirmed and suspected cases among residents reported to CMS as of May 31, 2020. *Degree* is the number of nursing homes that a particular home is connected to through a smartphone observed in both facilities. *Strength* is the total number of smartphones observed in a nursing home and other connected homes. *Weighted average neighbor degree* is the average number of connections a nursing home’s neighbor has, weighted by the pair strength. *Eigenvector centrality* measures the extent to which a nursing home’s neighbors are highly connected, and is calculated within each state and ranges from 0 to 1. Additional details are available in the Materials and Methods section.

Table S2. Detailed covariates of COVID case count specifications

	Dependent variable: $\sinh^{-1}(\text{Cases})$				
	(1)	(2)	(3)	(4)	(5)
<i>Beds</i>	0.00957*** (0.000744)	0.0103*** (0.000744)	0.00981*** (0.000737)	0.00936*** (0.000740)	0.0103*** (0.000744)
<i>Beds</i> ²	-0.00000554** (0.00000171)	-0.00000635** (0.00000172)	-0.00000533** (0.00000170)	-0.00000501** (0.00000170)	-0.00000621** (0.00000172)
<i>High proportion on Medicaid</i>	0.0891 (0.0456)	0.0925+ (0.0459)	0.0783 (0.0428)	0.0797 (0.0453)	0.0936 (0.0459)
<i>High proportion of Black residents</i>	0.526*** (0.0588)	0.547*** (0.0591)	0.491*** (0.0587)	0.489*** (0.0586)	0.563*** (0.0591)
<i>CMS rating 1</i>	-0.0656 (0.0701)	-0.0615 (0.0706)	-0.0685 (0.0698)	-0.0689 (0.0697)	-0.0650 (0.0706)
<i>CMS rating 2</i>	-0.0032 (0.0633)	0.00262 (0.0637)	-0.00924 (0.0630)	-0.0101 (0.0629)	-0.00423 (0.0637)
<i>CMS rating 3</i>	0.0593 (0.0634)	0.0681 (0.0638)	0.0592 (0.0631)	0.0558 (0.0630)	0.0609 (0.0638)
<i>CMS rating 4</i>	-0.0204 (0.0585)	-0.0141 (0.0589)	-0.0193 (0.0583)	-0.0216 (0.0582)	-0.0215 (0.0589)
<i>Has infection Violations</i>	-0.0750 (0.0505)	-0.0691 (0.0508)	-0.0677 (0.0503)	-0.0725 (0.0502)	-0.0783 (0.0508)
<i>Urban indicator</i>	0.734*** (0.0563)	0.782*** (0.0564)	0.662*** (0.0568)	0.656*** (0.0566)	0.770*** (0.0566)
<i>For profit indicator</i>	0.224*** (0.0495)	0.249*** (0.0497)	0.207*** (0.0493)	0.200*** (0.0492)	0.234*** (0.0498)
<i>Node degree</i>	0.0343*** (0.00255)			0.0242*** (0.00508)	
<i>Node strength</i>		0.0163*** (0.00166)		-0.00610+ (0.00297)	
<i>Weighted average neighbor degree</i>			0.0409*** (0.00267)	0.0299*** (0.00344)	
<i>Eigenvector centrality in state</i>					1.044*** (0.109)
<i>Fixed effects</i>	State	State	State	State	State
<i>Observations</i>	6,337	6,337	6,337	6,337	6,337
<i>F-stat</i>	123.4	114.9	128.7	112.9	114.5
<i>R²</i>	0.408	0.400	0.412	0.415	0.399
<i>Within R²</i>	0.189	0.178	0.195	0.199	0.177

Standard errors in parentheses. Significance levels: + $p < 0.05$, * $p < 0.01$, ** $p < 0.001$, *** $p < 0.0001$. Dependent variable is the inverse hyperbolic sine of COVID cases in a nursing home.

Table S3. Covariates of COVID-19 cases within nursing homes, by individual state

Dependent variable: $\sinh^{-1}(\text{Cases})$											
		CA		CT		CO		DC		FL	
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
<i>Node degree</i>		0.0262*** (0.00620)		0.0409+ (0.0193)		0.0188 (0.0320)		0.0872 (0.227)		0.0123 (0.00545)	
<i>Node strength</i>			0.0141** (0.00381)		0.0362+ (0.0172)		0.0207 (0.0263)		0.0190 (0.122)		0.00573 (0.00402)
<i>Observations</i>		1034	1034	199	199	178	178	17	17	575	575
<i>F-stat</i>		12.66	12.27	6.905	6.898	3.489	3.518	1.898	1.847	3.83	3.561
<i>R²</i>		0.130	0.126	0.308	0.308	0.202	0.204	0.760	0.755	0.076	0.0707

Dependent variable: $\sinh^{-1}(\text{Cases})$											
		GA		IL		KY		LA		MA	
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
<i>Node degree</i>		0.0474*** (0.0120)		0.0269*** (0.00592)		0.031 (0.0168)		0.0146 (0.0202)		0.0480*** (0.0113)	
<i>Node strength</i>			0.0125+ (0.00576)		0.0219*** (0.00509)		0.00340 (0.00782)		0.00950 (0.0155)		0.0403*** (0.00986)
<i>Observations</i>		338	338	637	637	256	256	202	202	363	363
<i>F-stat</i>		6.395	5.315	49.02	48.69	2.647	2.349	1.682	1.668	8.234	8.114
<i>R²</i>		0.191	0.164	0.485	0.484	0.116	0.104	0.097	0.0958	0.220	0.218

Dependent variable: $\sinh^{-1}(\text{Cases})$											
		MD		MI		MS		NC		ND	
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
<i>Node degree</i>		0.0195+ (0.00833)		0.0325 (0.0208)		-0.0539* (0.0204)		0.0131 (0.0110)		-0.026 (0.0438)	
<i>Node strength</i>			0.0140+ (0.00635)		0.0227 (0.0162)		-0.0296+ (0.0136)		0.000479 (0.00680)		-0.00984 (0.0196)
<i>Observations</i>		150	150	367	367	141	141	401	401	64	64
<i>F-stat</i>		6.16	6.082	12.2	12.15	1.454	1.253	1.994	1.871	4.473	4.455
<i>R²</i>		0.350	0.348	0.293	0.292	0.120	0.105	0.058	0.0547	0.486	0.485

Dependent variable: $\sinh^{-1}(\text{Cases})$											
		NH		NJ		PA		RI		SC	
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
<i>Node degree</i>		0.200* (0.0605)		0.00629 (0.0102)		0.0778*** (0.00971)		0.264** (0.0740)		0.0175 (0.0227)	
<i>Node strength</i>			0.180** (0.0506)		0.000707 (0.00752)		0.0188*** (0.00472)		0.208* (0.0646)		0.00129 (0.0143)
<i>Observations</i>		66	66	332	332	645	645	74	74	155	155
<i>F-stat</i>		3.152	3.359	10.8	10.76	25.86	20.41	4.108	3.775	0.68	0.629
<i>R²</i>		0.391	0.406	0.271	0.270	0.329	0.279	0.395	0.375	0.054	0.0505

Dependent variable: $\sinh^{-1}(\text{Cases})$					
		TN		WV	
		(1)	(2)	(1)	(2)
<i>Node degree</i>		0.00275 (0.0432)		0.0105 (0.0281)	
<i>Node strength</i>			0.00349 (0.0310)		0.0119 (0.0133)
<i>Observations</i>		40	40	103	103
<i>F-stat</i>		0.792	0.793	1.203	1.273
<i>R²</i>		0.260	0.261	0.127	0.133

Standard errors in parentheses. Significance levels: + $p < 0.05$, * $p < 0.01$, ** $p < 0.001$, *** $p < 0.0001$.

Dependent variable is inverse hyperbolic sine of COVID cases in the nursing home.

Demographics include number of beds, high proportion of Black residents, and high proportion on Medicaid.

CMS quality is a 1-5 categorical rating.

Table S4. Covariates of the existence of nursing home COVID-19 cases

	Dependent variable: Nursing home has > 0 cases				
	(1)	(2)	(3)	(4)	(5)
<i>Node degree</i>	0.00703*** (0.000679)			0.00410* (0.0013)	
<i>Node strength</i>		0.00319*** (0.000442)		-0.00167+ (0.000790)	
<i>Weighted average neighbor degree</i>			0.00981*** (0.000710)	0.00847*** (0.000915)	
<i>Eigenvector centrality in state</i>					0.180*** (0.0289)
<i>Fixed effects</i>	State	State	State	State	State
<i>Home demographics</i>	Yes	Yes	Yes	Yes	Yes
<i>CMS quality rating</i>	Yes	Yes	Yes	Yes	Yes
<i>Observations</i>	6,337	6,337	6,337	6,337	6,337
<i>F-stat</i>	76.02	70.87	83.88	72.64	69.60
<i>R²</i>	0.326	0.3146	0.335	0.336	0.319
<i>Within R²</i>	0.125	0.117	0.136	0.137	0.115

Standard errors in parentheses. Significance levels: ⁺ $p < 0.05$, $*p < 0.01$, $**p < 0.001$, $***p < 0.0001$. Dependent variable is a binary indicator that equals 1 if COVID cases are reported in a nursing home. Demographics include number of beds, high proportion of Black residents, and high proportion on Medicaid. CMS quality is a 1-5 categorical rating.

Table S5. Covariates of nursing home COVID-19 cases with county fixed effects

	Dependent variable: $\sinh^{-1}(Cases)$				
	(1)	(2)	(3)	(4)	(5)
<i>Node degree</i>	0.0193*** (0.00264)			0.0217*** (0.005088)	
<i>Node strength</i>		0.00937*** (0.00171)		-0.00304 (0.003066)	
<i>Weighted average neighbor degree</i>			0.0148*** (0.00313)	0.00318 (0.00373)	
<i>Eigenvector centrality in state</i>					0.684*** (0.119)
<i>Fixed effects</i>	County	County	County	County	County
<i>Home demographics</i>	Yes	Yes	Yes	Yes	Yes
<i>CMS quality rating</i>	Yes	Yes	Yes	Yes	Yes
<i>Observations</i>	5,967	5,967	5,967	5,967	5,967
<i>F-stat</i>	61.78	59.40	58.63	52.41	59.73
<i>R²</i>	0.569	0.567	0.566	0.569	0.567
<i>Within R²</i>	0.113	0.109	0.108	0.113	0.110

Standard errors in parentheses. Significance levels: ⁺ $p < 0.05$, $*p < 0.01$, $**p < 0.001$, $***p < 0.0001$. Dependent variable is inverse hyperbolic sine of COVID cases in the nursing home using individual state data. Demographics include number of beds, high proportion of Black residents, and high proportion on Medicaid. CMS quality is a 1-5 categorical rating.

Table S6. Covariates of COVID-19 cases within nursing homes using CMS data

	Dependent variable: $\sinh^{-1}(\text{Cases})$				
	(1)	(2)	(3)	(4)	(5)
<i>Node degree</i>	0.0207*** (0.00187)			0.0164*** (0.00300)	
<i>Node strength</i>		0.00639*** (0.000964)		-0.00219 (0.00135)	
<i>Weighted average neighbor degree</i>			0.0204*** (0.00190)	0.0120*** (0.00241)	
<i>Eigenvector centrality in state</i>					0.623*** (0.0759)
<i>Fixed effects</i>	State	State	State	State	State
<i>Home demographics</i>	Yes	Yes	Yes	Yes	Yes
<i>CMS quality rating</i>	Yes	Yes	Yes	Yes	Yes
<i>Observations</i>	13,165	13,165	13,165	13,165	13,165
<i>F-stat</i>	157.3	149.8	156.6	137.0	152.0
<i>R²</i>	0.258	0.253	0.257	0.259	0.254
<i>Within R²</i>	0.125	0.120	0.125	0.127	0.121

Standard errors in parentheses. Significance levels: $^+p < 0.05$, $*p < 0.01$, $**p < 0.001$, $***p < 0.0001$. Dependent variable is inverse hyperbolic sine of COVID cases in the nursing home using CMS data. Demographics include number of beds, high proportion of Black residents, and high proportion on Medicaid. CMS quality is a 1-5 categorical rating.

Fig. S1. Fraction of state nursing homes with a reported COVID-19 outbreak over time.

