Supplementary Appendix

1.1. Network Construction from Claims Data

Our network data comes from CareSet Systems who partners with the CMS in order to provide patient sharing network data for the Medicare population. That is, they utilize patient-provider encounter data (such as that available within claims data) can be viewed as a bipartite graph (see left graph in Figure below). This bipartite graph can in turn be used to obtain a single-partite graph projection (right graph in Figure below) in which providers are linked on the basis of shared patients. Following prior work (see e.g., Landon et al 2018, 2013, 2012), if we let **B** denote our bipartite patient-to-provider adjacency matrix, we define the provider-to-provider adjacency matrix as $\mathbf{A} = \mathbf{B}\mathbf{B}^{\mathbf{T}}$, where adjacency entries between providers are denoted as zero when links are missing, and 1 in cases where there are enough shared patients to indicate a professional patient sharing relationship between providers. Within our setting, such patient sharing relationships are present between providers who share 11 or more patients with one another.

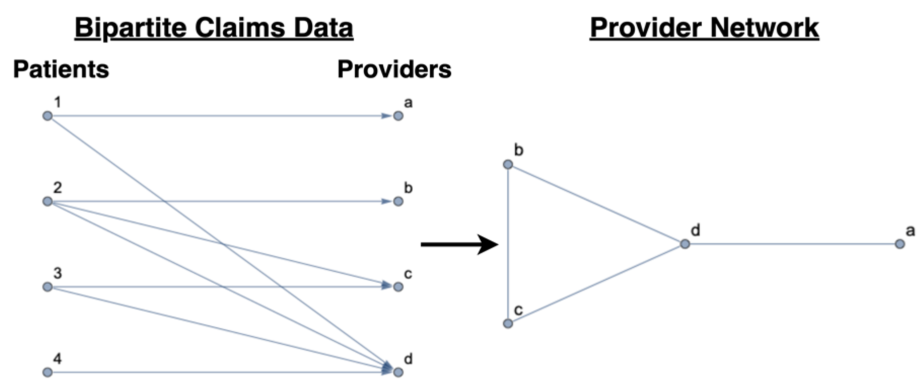

Figure S1: Mapping of Bipartite Patient-to-Provider Network Structure into Provider Network.

1.2. Network Measures Details

Three network measures are used to capture network structure within our analysis--one based on relative degree centrality, and two based on the overall network level centralization. The first of these is given by computing the county specific average degree centrality for primary care physicians (PCPs) and all non-PCP providers (based on a HRR level network), and then by taking the ratio of these two values at the county level. We define PCPs as providers reporting a primary specialty of family practice, general practice, pediatric medicine, internal medicine or obstetrics/gynecology within the national Medicare physician compare database. The degree of a provider (node) within the patient sharing network is given by the number of patient sharing ties (links) that that provider has with other providers/colleagues. As such, the degree of a provider tells us how connected that provider is within the network. In terms of its formal definition, the degree centrality for provider i in network g is given by: $C_i^{degree}(g) = \eta_i(g)$, where $\eta_i(g)$ denotes the degree of provider i in network g. Given this definition, our relative PCP to non-PCP centrality ratio is given by: $RC^{degree}(g) = \frac{C_{PCP}^{degree}(g)}{C_{NON-PCP}^{degree}(g)}$. As such, this measure will be higher in areas where the degree centrality of PCPs is higher relative to that of non-PCPs, which indicates that PCPs are relatively more central within these local provider structures. A similar measure has previously been employed within hospital and regional level analysis (see e.g. Landon et al. (2018), Barnett et al. (2012))

Second, we also use betweenness centralization and eigenvector centralization as our network measure. Betweenness centrality is defined at the provider level as: $C_i^{betwe}(g) = \frac{P_i(kj)/P(kj)}{(n-1)(n-2)/2}$, where $P_i(kj)$ captures the number of shortest paths between providers k and j within network g that provider i is on, and $P(kj)$ denotes the total number of shortest paths between k and j. As such, a provider will have a higher betweenness centrality if they occupy more of the shortest paths (i.e. if they stand on paths made up of relatively few links) connecting other providers within the network. Put differently, a provider with high betweenness centrality is important in terms of connecting other providers within the network.

Third, we use provider level eigenvector centrality, which is given by: $\lambda C_i^{eigen}(g) = \sum_j g_{ij} C_j^{eigen}(g)$, where λ is a proportionality factor, $C_j^{Eigen}(g)$ the eigenvector centrality of provider j and $g_{ij} = 1$ if providers i and j are connected within network g, and otherwise $g_{ij} = 0$. Here, a provider's importance (based on its centrality) is inferred from the importance of that provider's direct patient sharing colleagues -- that is, providers that are connected to well-connected colleagues receive a higher eigenvector centrality measure.

We also define a network (county) level centralization measure. For each centrality measure ($X \in \{Betweenness, Eigenvector\}$) the centralization of network g is given by: $C^X(g) = \frac{\sum_{i=1}^{n}(C_{i^*}^X(g) - C_i^X(g))}{max_{g\prime \in G}[\sum_{i=1}^{n}(C_{i^*}^X(g\prime) - C_i^X(g\prime))]}$, where i^* denotes the provider with the highest X centrality within network g. Important to note, is that this measure will be zero for networks where all providers occupy identical positions within the network, and it will increase with the level of global inequality within the specified network centrality measure.

A summary of these measures is furthermore provided within Table S1 below, and for additional references, please see e.g. Newman (2018), Jackson (2008), or Goyal (2012).

Measure Name	Measure Definition	Level	Details
Degree Centrality	$C_i^{degree}(g) = \eta_i(g)$	Provider	$\eta_i(g)$= degree of provider *i* in network *g*.
Betweenness Centrality	$C_i^{betwe}(g) = \frac{P_i(kj)/P(kj)}{(n-1)(n-2)/2}$	Provider	$P_i(kj)$=number of shortest paths between nodes *k* and *j* within network *g*. $P(kj)$=total number of paths between *k* and *j*.
Eigenvector Centrality	$\lambda C_i^{eigen}(g) = \sum_j g_{ij} C_j^{eigen}(g)$	Provider	λ=proportionality factor. $C_j^{eigen}(g)$= eigenvector centrality of node j. $g_{ij} = 1$ if nodes i and j are connected, and otherwise $g_{ij} = 0$.
Relative Centrality	$RC^X(g) = \frac{C_{PCP}^X(g)}{C_{NON-PCP}^X(g)}$	Network	$C_{group}^X(g)$=group-specific average degree centrality
Network Centralization	$C^X(g) = \frac{\sum_{i=1}^n (C_{i^*}^X(g) - C_i^X(g))}{max_{g\prime \in G}[\sum_{i=1}^n (C_{i^*}^X(g') - C_i^X(g'))]}$	Network	i^*denotes the node with the highest centrality (X)within network g.

Table S1: Main Network Measures and Their Definitions.

1.3. Histograms and Quartile Descriptives

Figure S2 provides histogram plots that trace out the distributions of our network measures (PCP/nonPCP degree centrality ratio, betweenness centralization, and eigenvector centralization). Table S2 provides additional quartile descriptives of these distributions, along with the mean of each COVID-19 measure across each of these network quartiles. Looking at the two-way t-test p-values – from a mean difference comparison across the first and fourth quartiles – we note significant variation within the network measure. We also find significant differences across the majority of our COVID-19 measures when comparing the mean outcomes of the first and fourth quartiles ($p<0.019$ in 8 out of 9 instances).

1.4. Network Measures, State Level Legislative and County Level Payor Differences

Two plausible channels of confounders pertaining to our measured network structure effects include: (i) state-level legislative differences across regions, and (ii) payor differences (for reference, see the DAG model within Figure 1). While our main analysis accounts for such state-level variation by including state fixed effects (indicator variables) within our regression analysis, we here present pairwise correlation results between our network measures and two sets of state-level legislative differences across U.S. states. The first set of legislative differences concern physician assistants (PAs). Here, we create state level indicator variables across 3 dimensions: 1) states that require a certain percentage of PAs to have their charts co-signed by physicians; 2) states with restrictions on the number of PAs that a physician can work with (so called ratio requirements); and 3) states where PAs have prescriptive authority for schedule 2 drugs (AMA, 2018). The pairwise correlations between these measures and our network measures are presented within Panel A of Table S3. Here we note a significant negative correlation ($p<0.01$) between PAs having prescriptive authority and the PCP/nonPCP Degree Centrality ratio only.

The second set of state-level legislative measures pertain to Nurse Practitioners (NPs). Here we similarly create state level indicator variable across 4 dimensions: 1) states where NPs have autonomy in their ability to provide patients with diagnosis and to prescribe medications; 2) states where NPs have full medical staff membership; 3) states where NPs can run a practice without the participation of a physician; and 4) states where NPs are recognized as PCPs (BA, 2019). The pairwise correlations between these legislative measures and our network measures can be seen within Panel B of Table S3. For the Eigenvector Centralization, we find negatively significant correlations across three out of our four NP legislation measures. This suggests that counties with higher eigenvector centralization tend to have more restrictive NP legislations, a feature that is captured within our analysis by the inclusion of our state fixed effects.

Lastly, we approximate variation in payor mix across counties using three county level measures form the County Health Rankins database. The first of these is the percentage of the population that is 65 or older. This measure captures the Medicare eligible population. The second measure is the percentage of individuals living in poverty, as an approximate of the percentage of the population eligible for Medicaid. The third measure is the percentage of the population that is uninsured – this captures the proportion of individuals that will qualify as self-paying individuals. The correlation between these measures and our network measures can be seen within the final panel (Panel C) of Table S3. Looking at the PCP/nonPCP degree centrality ratio and the betweenness centralization measures, we note that higher values for these measures are positively correlated with the majority of our proxies of payor shares. While many of these correlations are statistically significant, the magnitudes are at large modest.

1.5. Unadjusted Results

Supplementary Table S3 presents regression results adjusted for unobserved state level effects (which we do using fixed effects). In Panel A, our outcome measure is the COVID-19 mortality rate computed at the county population level. Here we find negative significant effects ($p<0.01$) across all three of our network measures. Looking first at the effect of a one standard deviation increase in the relative average PCP to non-PCP degree centrality ratio we note a reduction of 1.3 deaths per 100,000 (or a mortality rate reduction of 3.7%). Second, the effect of a one standard deviation increase in the betweenness centralization of a given provider network is associated with a decrease of 1.5 deaths per 100,000 (or a mortality rate reduction of 4.3%). Lastly, a one standard deviation increase in the eigenvector centralization of a provider network is associated with a decrease of 2.6 deaths per 100,000 (or a mortality rate reduction of 7.3%). As such, the effect due to a one standard deviation increase, depending on the network measure considered, range between a 1.3 to 2.6 deaths per 100,000 reduction in COVID-19 mortality (or a 3.7% to 7.3% decrease in the mortality rate).

For Panel B our outcome measure is instead the COVID-19 mortality rate based on the county cases. Again, we find negative significant effects across all three network measures ($p<0.1$, $p<0.05$, $p<0.05$). Depending on the network measure considered, we note effects (due to a one standard deviation increase in the network measure) that range between a 49.1 to 109.1 deaths per 100,000 reduction in COVID-19 mortality based on confirmed positive cases (or a 2.3% to 5.1% case-based mortality rate decrease).

Panel C provides estimates for the county population level COVID-19 case rates. Here we note significant relationships between the case rate and the provider networks' betweenness centralization ($p<0.01$), and the provider networks' eigenvector centralization ($p<0.05$). Based on the estimated point estimates, the effect due to a one standard deviation increase in the network measure ranges from a 25.5 to 42.0 cases per 100,000 reduction in confirmed COVID-19 cases (or a 1.7% to 2.8% case rate decrease).

1.6 Exploring the Source of Regional Heterogeneity within the Network Measures

Tables S4 – S6 present results that seek to provide further insight as to the source of network measure variability across counties. Each table focuses on one of the three network measures (PCP/nonPCP degree centrality ratio, betweenness centralization, eigenvector centralization). In order to explore how regions with high network measures differ from those with lower network measures, we present mean values for a number of community features across the network measure quartiles. We also provide the results from two-way t-test comparisons of the means between the bottom and top quartiles for each measure.

The community characteristics are combined into five groupings: 1) number of hospitals, which provides average hospital counts (across short term, long term and critical access hospitals) within these regions, sourced from the Department of Health & Human Services (HHS, 2020); 2) state-level PA legislations (as previously defined); 3) state-level NP legislations (as previously defined); 4) payor shares (as previously defined) and county level demographics (as previously defined). Looking at the results in Table S4, we see trends that help explain how communities with high and low relative PCP centrality differ.

First, we note that counties with a low (quartile 1) and high (quartile 4) PCP/nonPCP degree centrality ratio differ in terms of their organizational (hospital) resources. In particular, it appears that counties with a lower PCP/nonPCP degree centrality ratio tend to be associated with having more short-term and long-term stay facilities than those with a high ratio (p<0.0001). While the trend across quartiles is not as clear for critical access hospitals, it appears that areas with a lower PCP/nonPCP degree centrality ratio tend to have fewer of these hospitals than those in the top quartile. These findings suggest that network structure may correlate with regional organizational resources, a finding that appears aligned with prior work on physician patient sharing network formation identifying that shared organizational affiliations across hospitals, practices and systems are the main drivers of physicians sharing patients (see e.g. Linde (2019)). Second, we find that PA prescribing authority is more common (by about 8%) in areas with lower PCP/nonPCP degree centrality ratios. This provides some support for legislative differences influencing network structure – this argument appears to be further supported by results reported for our other network measures within Tables S5 & S6. Third, payor shares for Medicare, Medicaid and the uninsured is higher in regions with relatively more central PCPs. While these trends appear to be significantly different across the bottom and top quartiles, the percentage differences appear rather modest (ranging from a 1-2% differences depending on the measure). Lastly, pertaining to demographic differences, we note two particularly interesting variations. These are the findings that communities with more central PCPs tend to have a higher diabetes prevalence, and additionally a smaller percentage of Non-Hispanic Blacks. This suggest that access patterns to beneficial provider network structures may vary across racial and ethnic minority groups.

In summary, the observed descriptive patterns provide further qualitative support for our causal model (outlined within Figure 1), and in turn for our choice of control variables across population level health and demographics, as well as for our inclusion of state level fixed effects in order to capture latent health system and legislative differences across states within our main analysis.

1.7 County Level PCP/nonPCP Degree Centrality Ratio Results.

Within the main text, the PCP/nonPCP degree centrality ratios were constructed based on provider degree centrality measures from the hospital referral region network, which was then averaged across counties (and PCP/nonPCP groups) in order to construct our county level measure. An alternative approach to this measure construction would be to base use the degree centrality from a county level network. This was not done within the main text because computations based on hospital referral networks are more common within prior work, however, here we show that pursuing the alternative measurement creation approach yields qualitatively very similar results. This can be seen within Table S8, where the county level PCP/nonPCP degree centrality ratio is negatively (and statistically significantly) associated with each of our three COVID-19 outcome measures.

1.8 Network Measure Correlations and Geographic Associations

Table S9 indicates the correlation patterns between our network ratio and centralization measures. These are all significantly different from the null hypothesis of no pairwise correlation (p-value<0.001). Additionally, we note that these correlations are positive, indicating that counties with high (low) values for one measure tend to also have a high (low) value for the other measures. This patter is further seen across Figures S3 – S5, which present U.S. County Maps that are color coded on the basis of whether two (considered) measures are both in the top 50^{th} percentile of counties for that statistic, or whether both are in the bottom 50^{th} percentile of counties for the statistic. Areas where one of the statistics is in the top, while the other in the bottom, 50^{th} percentile (or cases of missing data) are marked in white. These figures bear out the trends seen within Figure 2 of the main text, but with more detail on the positive association between these measures across U.S. counties.

Supplementary Appendix References

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Supplementary Table S2: COVID-19 Outcome Descriptives and t-test Results By Network Measure Quartiles

Panel A: Descriptives By PCP/nonPCP Degree Centrality Ratio Quartiles

	PCP/nonPCP Degree Centrality Ratio	COVID-19 Mortality Rate - Population Level	COVID-19 Mortality Rate - Case Level	COVID-19 Case Rate - Population level
Quartile 1	0.50	37.29	2353.39	1517.24
Quartile 2	0.80	39.81	2476.62	1575.76
Quartile 3	1.16	31.08	2065.33	1426.41
Quartile 4	4.33	31.01	2025.24	1489.77
t-test Q1 Vs Q4 Mean Difference	p<0.0001	p=0.0085	p=0.0186	

Panel B: Descriptives By Betweenness Centralization Quartiles

	Betweenness Centralization	COVID-19 Mortality Rate - Population Level	COVID-19 Mortality Rate - Case Level	COVID-19 Case Rate - Population level
Quartile 1	6.89e-07	43.78	2781.79	1611.91
Quartile 2	0.00003	33.11	2278.46	1435.42
Quartile 3	0.00038	31.59	1985.07	1468.10
Quartile 4	0.03330	29.45	1817.82	1423.43
t-test Q1 Vs Q4 Mean Difference	p<0.0001	p<0.0001	p<0.0001	P=0.0058

Panel C: Descriptives By Eigenvector Centralization Quartiles

	Eigenvector Centralization	COVID-19 Mortality Rate - Population Level	COVID-19 Mortality Rate - Case Level	COVID-19 Case Rate - Population level
Quartile 1	0.08	41.09	2515.78	1600.13
Quartile 2	0.15	34.97	2307.20	1434.50
Quartile 3	0.23	33.48	2108.88	1486.87
Quartile 4	0.43	28.33	1928.22	1416.17
t-test Q1 Vs Q4 Mean Difference	p<0.0001	p<0.0001	p<0.0001	p=0.0056

P-values from two-sided t-tests (examining the mean difference between Quartile 1 and Quartile 4 values) are reported in cases where p<0.1

Quartile group observations range from 633 to 646 depending on network measure.

Supplementary Table S3: Pairwise Correlation Coefficients of Network Measures across: (A) State Level Physician Assistant Legislation; (B) State Level Nurse Practitioner Legislations; (C) County Level Payor Variation.

Network Measures:	PCP/nonPCP Degree Centrality Ratio	Betweenness Centralization	Eigenvector Centralization
Panel A: State Level Physician Assistant Legislations			
PA Charts Need Co-signature	-0.009	0.000	0.012
PA Ratio Requirements	-0.006	0.012	-0.025
PA Prescriptive Authority (Schedule 2)	-0.082***	0.001	-0.007
Panel B: State Level Nurse Practitioner Legislations			
NP Authorized to Provide Diagnosis/Prescribe	-0.031	0.019	-0.043**
NP Have Full Medical Staff Membership	-0.022	0.006	-0.034*
NP Can Run Autonomous Practice	-0.032	0.018	-0.044**
NP Recognized as PCP	-0.005	0.011	-0.003
Panel C: Payor Shares			
% 65 or Older	0.041**	0.094***	0.030
% in Poverty	0.049**	0.017	0.012
% Uninsured	0.064***	0.058***	0.016

Abbreviations: PA = Physician Assistant; NP = Nurse Practitioner

Significance of Correlation is indicated as: * p < 0.1, ** p < 0.05, *** p < 0.01

Supplementary Table S4: Regression Estimates from Models that only Adjust for State Fixed Effects.

	Model (1)	**Model (2)**	**Model (3)**
Panel A: COVID-19 Mortality Rate - Population Level			
Network Measures			
PCP/nonPCP Degree Centrality Ratio	-0.298*** (-0.499,-0.0962)		

Betweenness Centralization		-30.00*** (-48.07,-11.94)	
Eigenvector Centralization			-17.01*** (-25.17,-8.851)
Fixed Effects	Yes	Yes	Yes
N	2575	2543	2543
R^2	0.362	0.355	0.357
Panel B: COVID-19 Mortality Rate - Case Level			
Network Measures			
PCP/nonPCP Degree Centrality Ratio	-11.41* (-24.17,1.352)		
Betweenness Centralization		-1623.2** (-3119.8,-126.7)	
Eigenvector Centralization			-727.5** (-1283.1,-172.0)
Fixed Effects	Yes	Yes	Yes
N	2575	2543	2543
R^2	0.241	0.266	0.267
Panel C: COVID-19 Case Rate - Population level			
Network Measures			
PCP/nonPCP Degree Centrality Ratio	-5.927 (-14.73,2.871)		
Betweenness Centralization		-840.7*** (-1354.6,-326.8)	
Eigenvector Centralization			-277.1** (-503.4,-50.85)
Fixed Effects	Yes	Yes	Yes
N	2575	2543	2543
R^2	0.363	0.372	0.372

Significance is indicated as: * p < 0.1, ** p < 0.05, *** p < 0.01

Note: 95% confidence intervals are reported within the parentheses, and these are based on robust standard errors.

Supplementary Table S5: Descriptives Across PCP/nonPCP Degree Centrality Ratio Quartiles

	Quartile 1	**Quartile 2**	**Quartile 3**	**Quartile 4**	**t-test Q1 Vs. Q4**
Network Quartile Measure					
PCP/nonPCP Degree Centrality Ratio	0.50	0.80	1.16	4.33	p < 0.0001
Panel A: Number of Hospitals					
Number of Short Term Hospitals	2.48	1.71	0.78	0.44	p < 0.0001
Number of Long Term Hospitals	0.27	0.17	0.04	0.01	p < 0.0001
Number of Critical Access Hospitals	0.47	0.37	0.55	0.77	p < 0.0001
Panel B1: State-Level PA Legislations					
PA Charts Need Co-signature	0.43	0.42	0.49	0.47	
PA Ratio Requirements	0.81	0.80	0.76	0.77	
PA Prescriptive Authority (Schedule 2)	0.89	0.86	0.86	0.81	p = 0.0002
Panel B2: State-Level NP Legislations					
NP Authorized to Provide Diagnosis/Prescribe	0.24	0.23	0.28	0.27	
NP Have Full Medical Staff Membership	0.20	0.19	0.23	0.18	
NP Can Run Autonomous Practice	0.24	0.24	0.28	0.27	
NP Recognized as PCP	0.51	0.50	0.43	0.47	
Panel C: Payor Shares					
% 65 or Older	0.18	0.18	0.19	0.20	p < 0.0001
% in Poverty	0.13	0.13	0.14	0.15	p < 0.0001
% Uninsured	0.11	0.11	0.11	0.12	p = 0.0007
Panel D: Demographics					
% Females	0.50	0.50	0.50	0.50	p < 0.0001
% Non-Hispanic Black	0.10	0.10	0.08	0.08	p < 0.0001
Unemployment Rate	0.05	0.05	0.05	0.05	p < 0.0001
Diabetes prevalence	0.11	0.12	0.12	0.13	p < 0.0001
Mean Household Income	35604.08	34403.97	32154.97	31308.52	p < 0.0001

Abbreviations: PA = Physician Assistant; NP = Nurse Practitioner

P-values from two-sided t-tests (examining the mean difference between Quartile 1 and Quartile 4 values) are reported in cases where $p<0.1$

Supplementary Table S6: Descriptives Across Betweenness Centralization Quartiles

	Quartile 1	Quartile 2	Quartile 3	Quartile 4	t-test Q1 Vs. Q4
Network Quartile Measure					
Betweenness Centralization	6.89E-07	0.00003	0.00038	0.0333	p < 0.0001
Panel A: Number of Hospitals					
Number of Short Term Hospitals	3.44	1.03	0.52	0.33	p < 0.0001
Number of Long Term Hospitals	0.42	0.03	0.01	0.01	p < 0.0001
Number of Critical Access Hospitals	0.28	0.39	0.69	0.84	p < 0.0001
Panel B1: State-Level PA Legislations					
PA Charts Need Co-signature	0.44	0.46	0.43	0.47	
PA Ratio Requirements	0.82	0.76	0.76	0.79	
PA Prescriptive Authority (Schedule 2)	0.90	0.87	0.83	0.84	p = 0.0028
Panel B2: State-Level NP Legislations					
NP Authorized to Provide Diagnosis/Prescribe	0.22	0.23	0.29	0.28	p = 0.0077
NP Have Full Medical Staff Membership	0.19	0.20	0.20	0.21	
NP Can Run Autonomous Practice	0.22	0.24	0.29	0.28	p = 0.0115
NP Recognized as PCP	0.54	0.47	0.48	0.45	p = 0.0019
Panel C: Payor Shares					
% 65 or Older	0.17	0.19	0.19	0.20	p < 0.0001
% in Poverty	0.12	0.13	0.15	0.15	p < 0.0001
% Uninsured	0.10	0.10	0.11	0.12	p < 0.0001
Panel D: Demographics					
% Females	0.51	0.50	0.50	0.50	p < 0.0001
% Non-Hispanic Black	0.11	0.08	0.08	0.08	p < 0.0001
Unemployment Rate	0.05	0.05	0.05	0.05	p < 0.0001
Diabetes prevalence	0.11	0.12	0.12	0.13	p < 0.0001
Mean Household Income	37711.95	33690.21	31485.80	30940.76	p < 0.0001

Abbreviations: PA = Physician Assistant; NP = Nurse Practitioner

P-values from two-sided t-tests (examining the mean difference between Quartile 1 and Quartile 4 values) are reported in cases where p<0.1

Supplementary Table S7: Descriptives Across Eigenvector Centralization Quartiles

	Quartile 1	**Quartile 2**	**Quartile 3**	**Quartile 4**	**t-test Q1 Vs. Q4**
Network Quartile Measure					
Eigenvector Centralization	0.08	0.15	0.23	0.43	p < 0.0001
Panel A: Number of Hospitals					
Number of Short Term Hospitals	1.84	2.24	0.75	0.58	p < 0.0001
Number of Long Term Hospitals	0.24	0.20	0.04	0.02	p < 0.0001
Number of Critical Access Hospitals	0.37	0.40	0.71	0.67	p < 0.0001
Panel B1: State-Level PA Legislations					
PA Charts Need Co-signature	0.46	0.45	0.44	0.45	
PA Ratio Requirements	0.81	0.78	0.78	0.76	p = 0.0277
PA Prescriptive Authority (Schedule 2)	0.86	0.89	0.84	0.86	
Panel B2: State-Level NP Legislations					
NP Authorized to Provide Diagnosis/Prescribe	0.23	0.27	0.32	0.21	
NP Have Full Medical Staff Membership	0.20	0.22	0.21	0.18	
NP Can Run Autonomous Practice	0.23	0.28	0.33	0.21	
NP Recognized as PCP	0.45	0.52	0.49	0.48	
Panel C: Payor Shares					
% 65 or Older	0.19	0.18	0.19	0.19	
% in Poverty	0.14	0.13	0.14	0.14	
% Uninsured	0.12	0.10	0.11	0.11	

Panel D: Demographics					
% Females	0.50	0.50	0.50	0.50	p < 0.0001
% Non-Hispanic Black	0.11	0.09	0.08	0.08	p = 0.0001
Unemployment Rate	0.05	0.05	0.05	0.05	
Diabetes prevalence	0.12	0.11	0.12	0.13	p=0.0283
Mean Household Income	34237.59	35185.77	32449.73	31956.36	p < 0.0001

Abbreviations: PA = Physician Assistant; NP = Nurse Practitioner

P-values from two-sided t-tests (examining the mean difference between Quartile 1 and Quartile 4 values) are reported in cases where $p<0.1$

Supplementary Table S7: Summary Statistics for PCP/nonPCP Degree Centrality ratios computed based on county networks.

Network Measures	**Mean**	**Std. Dev.**	**Observations**
Number of Nodes (County)	280.63	798.10	2,511
Number of Links (County)	9,998.62	36,086.73	2,511
PCP/nonPCP Degree Centrality Ratio	1.12	0.44	2,456

Supplementary Table S8: Regression Estimates Across Outcome and county level PCP/nonPCP Degree Centrality Ratio Models.

	Model (1) COVID-19 Mortality Rate - Population Level	**Model (2) COVID-19 Mortality Rate - Case Level**	**Model (3) COVID-19 Case Rate - Population Level**
Network Measures			
PCP/nonPCP Degree Centrality Ratio	-5.612*** (-8.625,-2.601)	-292.793*** (-467.182, -118.404)	-89.369** (-172.035,-6.703)
County Level Controls Included	Yes	Yes	Yes
Fixed Effects	Yes	Yes	Yes
N	2449	2449	2449
R^2	0.429	0.285	0.509

Significance is indicated as: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

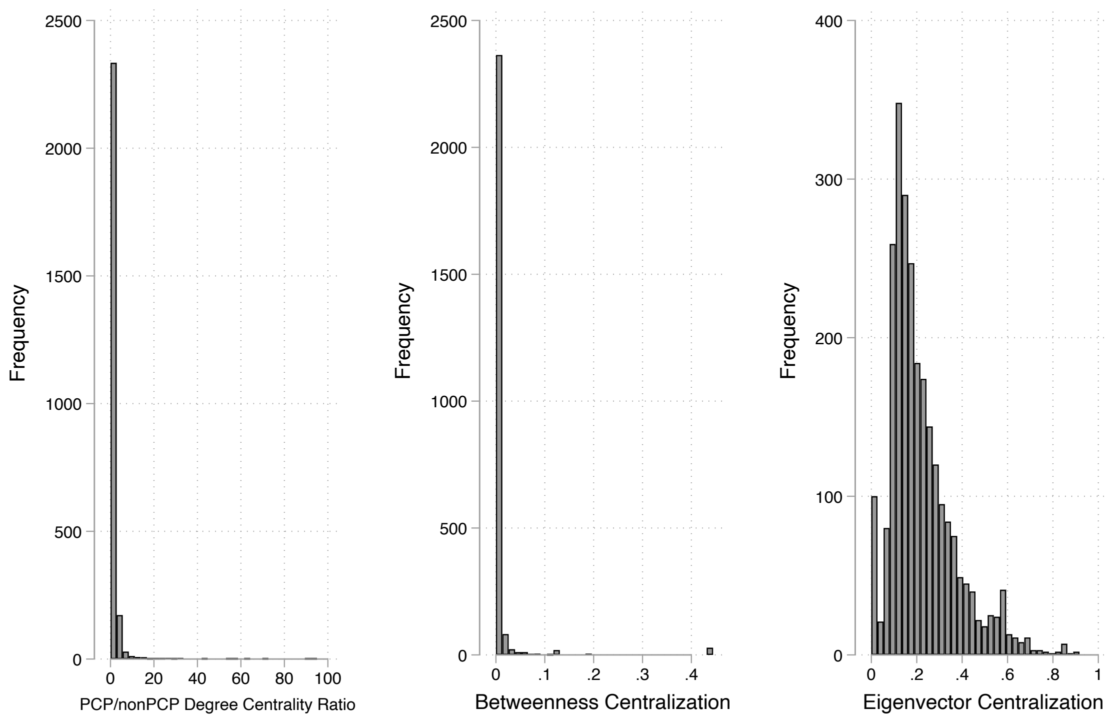
Note: 95% confidence intervals are reported within the parentheses, and these are based on robust standard errors.

Supplementary Table S9: Pairwise Correlations across network ratio and centralization measures.

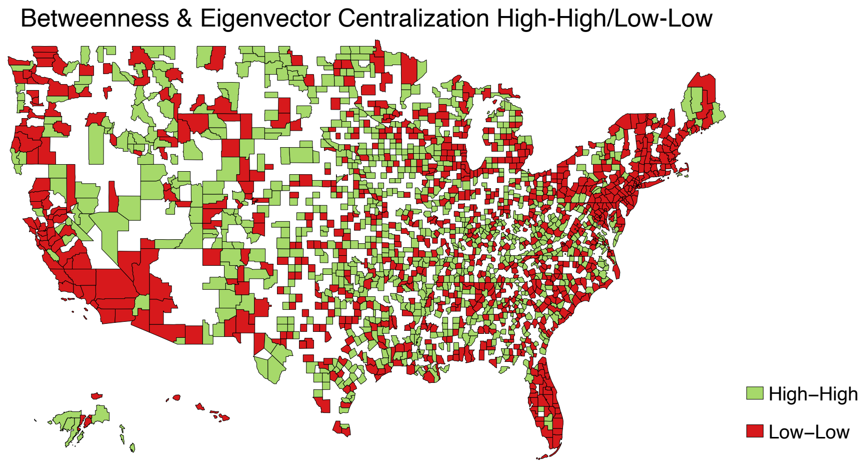
	PCP/nonPCP Degree Centrality Ratio	Betweenness Centralization	Eigenvector Centralization
PCP/nonPCP Degree Centrality Ratio	1.00	-	-
Betweenness Centralization	0.27***	1.00	-
Eigenvector Centralization	0.15***	0.33***	1.00

Note: *** denotes pairwise correlations that are significantly different from the null hypothesis of a zero correlation at the p-value<0.001 level.

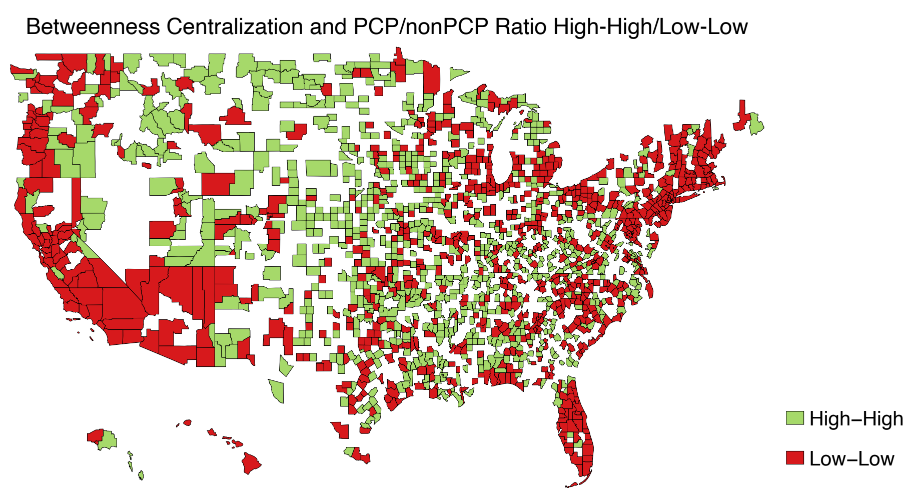
Supplementary Figure S2: Histogram Plots of Network Measures



Supplementary Figure S3: U.S. Between County Map. In Green we see counties with high Betweenness and Eigenvector Centralization. In Red we see counties with low Betweenness and Eigenvector Centralization.



Supplementary Figure S4: U.S. Between County Map. In Green we see counties with high Betweenness Centralization and PCP/nonPCP degree centrality Ratio. In Red we see counties with low Betweenness Centralization and PCP/nonPCP degree centrality Ratio.



Supplementary Figure S5: U.S. Between County Map. In Green we see counties with high Eigenvector Centralization and PCP/nonPCP degree centrality Ratio. In Red we see counties with low Eigenvector Centralization and PCP/nonPCP degree centrality Ratio.

Eigenvector Centralization and PCP/nonPCP Ratio High-High/Low-Low