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Zhaowei SHE

Singapore Management University, zwshe@smu.edu.sg

Anne H. GAGLIOTI

Peter BALTRUS

Chaohua LI

Miranda A. MOORE

*See next page for additional authors*

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#### Citation

SHE, Zhaowei; GAGLIOTI, Anne H.; BALTRUS, Peter; LI, Chaohua; MOORE, Miranda A.; IMMERGLUCK, Lilly C.; RAO, Arthi; and AYER, Turgay. Primary care comprehensiveness and care coordination in robust specialist networks results in lower emergency department utilization: A network analysis of Medicaid physician networks. (2020). *Journal of Primary Care & Community Health*. 11, 1-9.  
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**Author**

Zhaowei SHE, Anne H. GAGLIOTI, Peter BALTRUS, Chaohua LI, Miranda A. MOORE, Lilly C. IMMERGLUCK, Arthi RAO, and Turgay AYER

# Primary Care Comprehensiveness and Care Coordination in Robust Specialist Networks Results in Lower Emergency Department Utilization: A Network Analysis of Medicaid Physician Networks

Journal of Primary Care & Community Health  
Volume 11: 1–9  
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sagepub.com/journals-permissions  
DOI: 10.1177/2150132720924432  
journals.sagepub.com/home/jpc  


Zhaowei She<sup>1</sup>, Anne H. Gaglioti<sup>2</sup> , Peter Baltrus<sup>2</sup>, Chaohua Li<sup>2</sup>,  
Miranda A. Moore<sup>3</sup>, Lilly C. Immergluck<sup>2</sup>, Arthi Rao<sup>1</sup>, and Turgay Ayer<sup>1</sup>

## Abstract

**Background:** Care coordination is an essential and difficult to measure function of primary care. **Objective:** Our objective was to assess the impact of network characteristics in primary/specialty physician networks on emergency department (ED) visits for patients with chronic ambulatory care sensitive conditions (ACSCs). **Subjects and Measures:** This cross-sectional social network analysis of primary care and specialty physicians caring for adult Medicaid beneficiaries with ACSCs was conducted using 2009 Texas Medicaid Analytic eXtract (MAX) files. Network characteristic measures were the main exposure variables. A negative binomial regression model analyzed the impact of network characteristics on the ED visits per patient in the panel. **Results:** There were 42 493 ACSC patients assigned to 5687 primary care physicians (PCPs) connected to 11 660 specialist physicians. PCPs whose continuity patients did not visit a specialist had 86% fewer ED visits per patient in their panel, compared with PCPs whose patients saw specialists. Among PCPs connected to specialists in the network, those with a higher number of specialist collaborators and those with a high degree of centrality had lower patient panel ED rates. **Conclusions:** PCPs providing comprehensive care (ie, without specialist consultation) for their patients with chronic ACSCs had lower ED utilization rates than those coordinating care with specialists. PCPs with robust specialty networks and a high degree of centrality in the network also had lower ED utilization. The right fit between comprehensiveness of primary care, care coordination, and adequate capacity of specialty availability in physician networks is needed to drive outcomes.

## Keywords

primary care, care coordination, social network analysis, Medicaid

Dates received 5 February 2020; revised 8 April 2020; accepted 8 April 2020.

## Introduction

Robust primary care systems are associated with lower overall mortality, lower health care costs, better health care quality, and less health inequity.<sup>1–5</sup> Primary care occurs in the context of a health care ecosystem and requires care coordination across the full spectrum of health care service delivery and the socio-ecologic infrastructure of communities and populations. Understanding the impact of care coordination on the health of people and populations can inform best practices for design of physician networks and health care systems.

One aspect of this complex system includes networks of primary care and specialist physicians caring for patients. Coordinated care between primary care and specialist

clinicians supports good health outcomes for patients with chronic illnesses.<sup>6–9</sup> Additionally, specialty referral networks characterized by fewer, more deliberate connections with more frequent contacts have lower costs and better quality.<sup>10</sup> However, few studies have explored network characteristics of health care providers<sup>11</sup> and even fewer

<sup>1</sup>Georgia Institute of Technology, Atlanta, GA, USA

<sup>2</sup>Morehouse School of Medicine, Atlanta, GA, USA

<sup>3</sup>Emory University, Atlanta, GA, USA

### Corresponding Author:

Anne H. Gaglioti, National Center for Primary Care, Morehouse School of Medicine, 720 Westview Drive, SW, Atlanta, GA 30310, USA.  
Email: agaglioti@msm.edu



have focused on networks of primary and specialty providers in outpatient clinical settings, where a majority of health care occurs.<sup>12</sup> One study of Medicare provider networks found inconsistent relationships between the physician network characteristics and quality of care and costs; in this study, however, they did not address primary/specialty care networks.<sup>13</sup>

The purpose of this study was to measure the impact of primary and specialty physician network infrastructure on health outcomes for patients with ambulatory care sensitive chronic diseases through a social network analysis. Specifically, we sought a mechanism to measure the impact of care coordination on patients with chronic illnesses in primary care. We focused on the network of primary care and specialty physicians caring for adult Medicaid beneficiaries with chronic ambulatory care sensitive conditions (ACSCs)<sup>14</sup> in Texas in 2009. Our analysis is the first to quantify care coordination networks of primary care physicians (PCPs) and specialist physicians via the network characteristics of their patient sharing patterns and assess these network measures in predicting health care utilization outcomes among PCP panels of Medicaid beneficiaries with ACSCs. This work can inform structuring of primary care and specialty physician networks, and resulting network interactions, to facilitate improvement in health outcomes in state Medicaid programs and the broader health care system.

## Methods

### Overview and Data Source

We used 2009 Texas Medicaid Analytic eXtract (MAX) files to conduct a cross-sectional network analysis that measured the impact of physician network characteristics on emergency department (ED) utilization. Networks are characterized by nodes and connections between them. Social Network Analysis (SNA) is a methodological tool that quantifies and describes the configuration of these nodes and the pattern of connections between them. MAX files include information on Medicaid eligibility, health care utilization, and payments in a common data format. This study used outpatient files, inpatient files, and personal summary files linked by a common identifier. We used the National Physician Identifier (NPI) linked with the National Plan and Provider Enumeration System (NPPES) database to identify physicians as primary care or specialty providers. (See Appendix A for a listing of provider taxonomies.)

Texas was chosen for its relatively large physician network, high rate of continuity of care for Medicaid beneficiaries with ACSC based and a relatively random patient assignment across PCPs on exploratory analysis of our 29 state MAX file data. Specifically, starting from February 2007, Texas Medicaid introduced a county-level mandate that required its disabled Medicaid beneficiaries to switch

from public to private plans, which created a quasi-random assignment of patients in later years.<sup>15</sup> Each eligible patient was assigned to a unique PCP. A patient-sharing network was constructed where PCPs and specialists were connected if they had cared for common patients. Finally, we estimated the association between ED utilization of primary care patients and standard network measures at the PCP level. This analysis was conducted through a data use agreement with Centers for Medicare and Medicaid Services and received institutional review board approval.

### Identification of Eligible Patients

We applied the following inclusion criteria for patients: (1) age 18 to 64 years; (2) nondual eligible; (3) at least 3 chronic ACSC related visits to a PCP in a 12-month period (ACSC listed as first or second diagnosis code for claim); (4) at least 2 visits with the most seen PCP for ACSC; (5) at least 50% of total PCP visits for ACSC were with the most seen PCP; and (6) continuously enrolled in Medicaid during 2009. ACSC were identified using *International Classification of Diseases, Ninth Revision, Clinical Modification codes* and are available in Appendix B. A patient was considered to have a chronic ACSC if they had at least 2 outpatient claims or 1 inpatient claim for the condition in a 12-month period. The selection of ACSC conditions were based on a list of conditions defined by the National Academies of Medicine.<sup>14</sup> We included chronic conditions that could be managed via chronic disease management in primary care or specialty outpatient setting.

### Assigning Eligible Patients to PCPs

To enable fair performance evaluation of PCPs for care coordination, each eligible patient was assigned to a PCP if the patient had at least 2 ACSC related visits to the PCP and the PCP accounted for at least half of the patient's total PCP visits in 2009. We restricted the analysis to chronic ACSCs because better primary care leads to lower adverse outcomes for these conditions.<sup>16,17</sup> We excluded patients without continuity for chronic disease management, as PCPs would have minimal opportunities to coordinate care with specialists for these patients. As such, we only included patients who met our criteria for having continuity of care for chronic disease management and thus had adequate primary care access in the study sample.

### Construction of the Physician Network

We constructed a bipartite graph between PCPs and specialists, where the connections were defined by common patients, and weighted by the number of these common patients.<sup>18</sup> If a patient visited a specialist, the PCP of this patient would be connected to the specialist in the network. The graph identified was undirected.

## Measures of Interest

Patient and physician network information were aggregated to the PCP level. The final sample contained observations from the set  $I$  of 5687 PCPs. For each PCP  $i \in I$ , we calculated the following measures:  $Y_i^{ED}$ ,  $X_i^{Eigen}$ ,  $X_i^{Degree}$ ,  $I_i^{Solo}$ ,  $X_i^{Patients}$ ,  $X_i^{Age}$ ,  $X_i^{Eci}$ ,  $X_i^{Acs}$ ,  $X_i^{MC}$  and  $X_i^{FFS}$ .  $Y_i^{ED}$  counted the number of ED visits in 2009 from patients with chronic ACSCs in PCP  $i$ 's panel. ED visits were identified by meeting any of the following codes for professional claims: (1) place of service code = 23; (2) revenue codes = 450-459, 981; or (3) Current Procedural Terminology (CPT) codes = 99281-99285. The main outcome variable after accounting for the size of the PCP's panel was the number of ED visits per patient in each PCP's panel. The main predictors measuring the patient-sharing network were  $X_i^{Eigen}$ ,  $X_i^{Degree}$  and  $I_i^{Solo}$ .  $X_i^{Eigen}$  ranges in value from 0 to 1 and measures the eigenvector centrality of PCP  $i$  in the patient-sharing network. Eigenvector centrality is a common index used in rating systems such as Google PageRank, which measures the quality and quantity of links to a webpage.<sup>19</sup> Similarly,  $X_i^{Eigen}$  here captured the quality and quantity of specialists with whom a PCP  $i$  has shared patients. The higher a PCP's eigenvector centrality, the more likely this PCP is sharing patients with specialists who perform better in care coordination. Initially, our analysis produced a connected component that accounted for more than 95% of the non-isolated nodes (PCPs). It was unlikely 95% of the PCPs in Texas practiced in the same community. To produce a centrality measure more reflective of the real world, we used a community detection algorithm.<sup>20</sup> We selected the spin glass algorithm as it produced the best clustering model in terms of modularity measure.  $X_i^{Degree}$  identified the number of specialists with whom PCP  $i$  coordinated care.  $I_i^{Solo}$  indicated patients in PCP  $i$ 's panel did not visit a specialist. This measure is based on claims-based measures of primary care comprehensiveness that identify involvement in care by identifying the proportion of care in primary versus specialty care settings.<sup>21</sup> The  $I_i^{Solo}$  measure identified PCPs who provided all chronic disease management for their panels of patients with chronic ACSCs without specialist involvement. Variables  $X_i^{Patients}$ ,  $X_i^{Age}$ ,  $X_i^{Eci}$ ,  $X_i^{Acs}$ ,  $X_i^{MC}$  and  $X_i^{FFS}$  were included to control for confounding patient and physician characteristics.  $X_i^{Patients}$  counted the number of patients in PCP  $i$ 's panel.  $X_i^{Age}$  was the percentage of patients aged 55 years or older.  $X_i^{Eci}$  was the average Elixhauser Comorbidity Index (ECI) of patients in the panel. ECI is a validated measure of disease burden and predicts risk by using administrative claims data.<sup>22</sup>  $X_i^{Acs}$  was the average number ACSCs per patient in the panel.  $X_i^{MC}$  was the percentage of patients in the panel who spent more than 6 months in Medicaid managed care in 2009.  $X_i^{FFS}$  was the percentage of patients in PCP  $i$ 's panel who spent more than 6 months in Medicaid fee-for-service in 2009.

## Statistical Analysis

Descriptive statistics were generated and a 2-sample  $t$ -test compared the characteristics of PCPs who provided solo care to their ACSC patient panels to those who coordinated care for ACSC panels with specialists. A negative binomial regression model was constructed to show the association between patient-sharing network characteristics and the number of ED visits per patient in a PCP's panel of ACSC. We estimated the following model:

$$P(\mathbf{Y}_i^{ED} | X) = NB \left( \begin{array}{l} \beta_0 + \beta_1 X_i^{Eigen} + \beta_2 X_i^{Degree} + \beta_3 X_i^{Eigen} \times \\ X_i^{Degree} + \beta_4 I_i^{Solo} + \beta_5 X_i^{Patients} + \beta_6 X_i^{Age} + \\ \beta_7 X_i^{Eci} + \beta_8 X_i^{Acs} + \beta_9 X_i^{MC} + \beta_{10} X_i^{FFS} + \\ \ln(X_i^{Patients}) \end{array} \right)$$

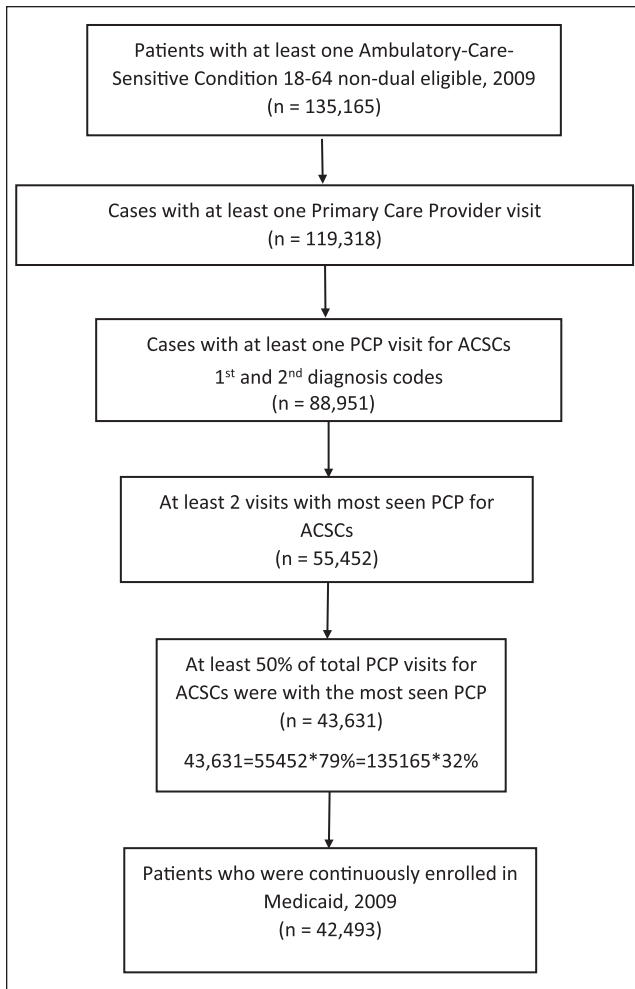
where  $NB(\ln(\mu_i))$  was a negative binomial distribution with  $\mu_i = E[\mathbf{Y}_i^{ED}]$ . The unit of analysis was PCP  $i \in \{1, \dots, 5687\}$ . The last term,  $\ln(X_i^{Patients})$ , was the offset. Here negative binomial regression is a class of generalized linear models whose dependent variable consists of count data.<sup>23</sup> Particularly, the negative binomial model is a generalization of the Poisson model, which assumes that the mean and variance of the dependent variable are equal. We have performed the overdispersion test and rejected this assumption of the Poisson model in our study sample ( $P < .01$ ). Therefore, a negative binomial model was preferred over a Poisson model in this study.

All  $P$  values were 2-sided and a  $P$  value  $< .05$  was considered statistically significant. SAS version 9.4 (SAS Institute, Inc) was used to perform all analyses except for the community detection algorithm, which was conducted using the R programming language.

## Results

There were 5687 PCPs providing continuity of care for ACSC to 42493 adult Texas Medicaid beneficiaries with chronic ACSCs. These PCP coordinated care for these patients with 11660 specialists. Figure 1 outlines the detailed inclusion criteria and final sample counts. The final sample accounts for 31% of the total Texas Medicaid patients in 2009. In all, 32% of the Texas Medicaid patients with ACSCs met our criteria for interpersonal continuity of care for chronic disease management with a PCP.

Table 1 presents descriptive statistics and definitions of network characteristics, for ease of interpretation. Separate statistics are calculated for patients with and without visits to specialists in 2009 because the dependent variable responded differently to network characteristics in the subgroups characterized by those PCPs who did not share any ACSC patients with specialists and those PCPs who coordinated care for ACSC patients with specialists.



**Figure 1.** Patient inclusion criteria and cascade used to identify continuity primary care physician (PCP) panels of adult Medicaid beneficiaries in Texas in 2009 with chronic ambulatory care sensitive conditions (ACSCs).

Table 2 shows the gender ratio and practice locations of PCPs and specialists. The PCP group had more females and more practices in rural and health professional shortage areas (HPSAs) than the specialist group. Figure 2 draws 2 connected components of the constructed patient sharing networks. Panel B illustrates the community detection algorithm. The algorithm partitions this component into 5 independent components (labeled by different colors), where edges between different components are essentially deleted. Panel A shows the largest component identified by the community detection algorithm, where red and blue vertex represent PCPs and specialists, respectively.

Estimation results from the negative binomial regression model are presented in Table 3. PCPs who were the sole health care providers of their patients tend to have lower patient panel ED rates. Specifically, if a PCP provided comprehensive care for ACSC patients, this PCP would have

86% lower patient panel ED rates than a similar PCP who coordinated care with specialists (we calculated the incidence of ED visit rate ratio equal to  $1 - \exp[-1.98]$ ). Among PCPs with patients who saw specialists, those who had a higher number of specialist collaborators and those who had a high degree of eigenvector centrality (“high quality” hubs connected with “high quality” specialist collaborators) had lower patient panel ED rates. Eigenvector centrality is a measure of the level of influence of a node in a social network, it is based on not only the number of connections to other nodes but also how influential those nodes are in the network. In this case, we can think of a PCP with high eigenvector centrality as being a hub connected to influential specialists, or those that also share patients with other PCPs in the network.<sup>24</sup> There was an interaction effect between centrality and the number of specialists. PCPs with higher eigen centrality did not necessarily have lower ED rates in their patient panels. If a PCP collaborated with a limited number of specialists ( $X_i^{Degree}$ ), higher eigen centrality ( $X_i^{Eigen}$ ) was associated with higher ED rates. Conversely, if a PCP had low eigen centrality, or coordinated chronic disease care with less influential specialist collaborators ( $X_i^{Eigen}$ ), a PCP who had more specialists collaborators ( $X_i^{Degree}$ ) had higher ED visit rates. ED visit rates were negatively associated with the number of specialist collaborators if the PCP had a eigenvector centrality ( $X_i^{Eigen}$ ) of at least 0.49 (ie,  $\beta_2 + \beta_3 X_i^{Eigen} < 0$ ); ED rates were negatively associated with the eigenvector centrality of a PCP if the number of specialist collaborators ( $X_i^{Degree}$ ) was at least 113 (ie,  $\beta_1 + \beta_3 X_i^{Degree} < 0$ ). For example, a PCP with ten specialist collaborators ( $X_i^{Degree} = 10$ ) who was less influential in the physician network ( $X_i^{Eigen} = 0.1$ ) had 184% higher ED visit rates in his or her patient panel than a PCP with 5 specialist collaborators and the same level of influence in the network set of specialist collaborators (we calculated the incidence rate ratio equal to the  $\exp[0.0114 * 10 - 0.0235 * 0.1 * 10] / \exp[0.0114 * 5 - 0.0235 * 0.1 * 5]$ ). It is important to note that a measure of comorbidity of the physician’s patient panel is accounted for in the model.

## Discussion

We found Texas PCPs providing solo care for Medicaid patients with ACSCs without specialist collaboration had the lowest rates of ED utilization. PCPs with adequate specialist networks available and a high degree of centrality, which can be thought of as robust opportunity for care coordination with specialists who were influential in the network, in their provider networks also had lower ED utilization rates. The rightness of fit between primary care centrality or the influence of the PCP and their collaborating specialist colleagues and the robustness of the specialist networks available was an important driver of ED utilization.



**Table 1.** Description of the Social Network Characteristics of Primary Care Physicians (PCPs) and their Panels of Adult Medicaid Beneficiaries with Chronic Ambulatory Care Sensitive Conditions (ACSCs) in Texas, 2009 (n = 5687 PCPs).

| Variable         | Definition   | Summary statistics                                  |  |                                |
|------------------|--|---|--|--------------------------------|
|                  |  | ACSC patient panels managed by PCP alone (n = 1020) | ACSC patient panels with PCP specialist care coordination (n = 42 473) | All ACSC patients (n = 42 493) |
| $Y_i^{ED}$       | Number of ED visits in PCP <i>i</i> 's panel   | 0.864   | 1.832  | 1.794                          |
| $X_i^{Eigen}$    | Eigenvector centrality of PCP <i>i</i> 's in the patient-sharing network   | 1   | 0.141  | 0.176                          |
| $X_i^{Degree}$   | The number of specialists with whom PCP <i>i</i> coordinated care  | 0   | 32.396   | 31.097                         |
| $I_i^{Solo}$     | PCP <i>i</i> cares for ACSC panel without specialists (binary indicator)   | 1   | 0  | 0.401                          |
| $X_i^{Patients}$ | Number of ACSC patients in PCP panel   | 4.474   | 7.597  | 7.472                          |
| $X_i^{Age}$      | The percentage of patients in PCP's panel aged 55 years and older  | 0.308   | 0.387  | 0.385                          |
| $X_i^{Eci}$      | Average Elixhauser Comorbidity Index <sup>a</sup> of patients in PCP <i>i</i> 's panel                             | 2.667   | 2.917  | 2.911                          |
| $X_i^{Acs}$      | The average number of patients with ACSC in PCP <i>i</i> 's panel  | 1.981   | 1.764  | 1.768                          |
| $X_i^{MC}$       | The proportion of patients in PCP <i>i</i> 's panel who spent more than 6 months in Medicaid managed care          | 0.564   | 0.598  | 0.578                          |
| $X_i^{FFS}$      | The proportion of patients in PCP <i>i</i> 's panel who spent more than 6 months in Medicaid fee-for-service (FFS) | 0.300   | 0.279  | 0.280                          |
| Rural            | The proportion of PCPs who practiced in rural areas  | 0.225   | 0.161  | 0.162                          |

<sup>a</sup>Elixhauser Comorbidity Index is a measure of medical complexity that predicts mortality and utilization ranging from 0 to 31, a higher number indicates higher complexity.

**Table 2.** Characteristics of Primary Care Physicians (PCPs) and Specialists caring for Adult Medicaid Beneficiaries With Chronic Ambulatory Care Sensitive Conditions in Texas, 2009.

|                 | PCP characteristics (n = 10 665) | Specialist characteristics (n = 11 709) | Two-sample t tests (P value) |
|-----------------|----------------------------------|---|------------------------------|
| Percent female  | 22.1                             | 20.4                                    | .07                          |
| Missing         | 0.098                            | 0.059                                   |                              |
| Percent rural   | 14.4                             | 9.4                                     | <.01                         |
| Missing         | 0.001                            | 0.001                                   |                              |
| Percent in HPSA | 7.5                              | 3.0                                     | <.01                         |
| Missing         | 0.282                            | 0.322                                   |                              |

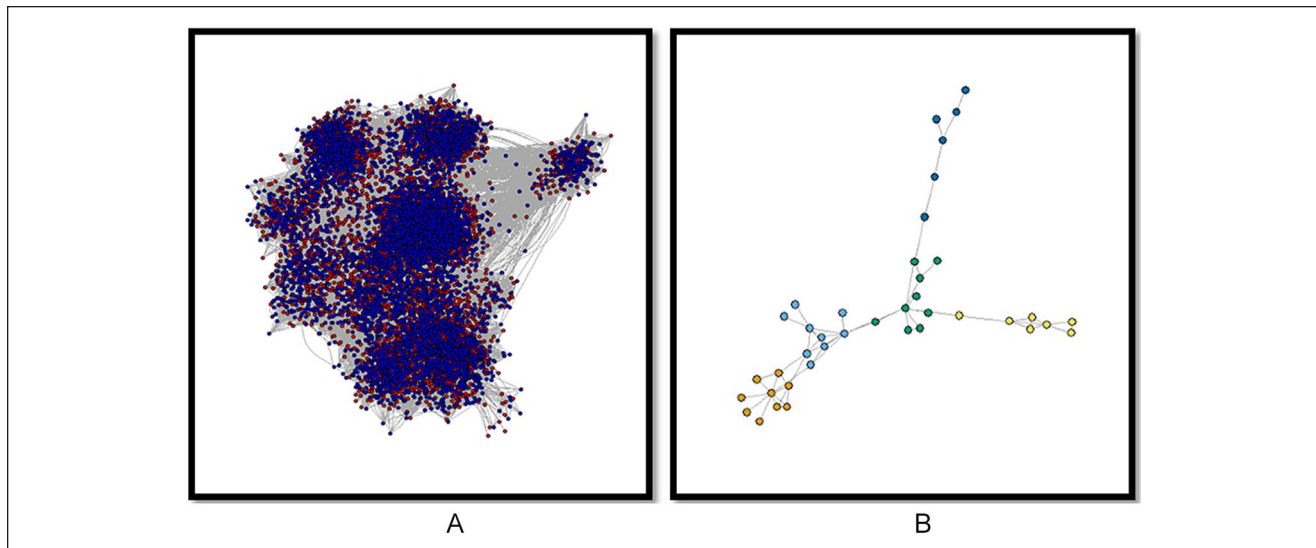
Abbreviation: HPSA, health professional shortage area.

One unique aspect of this analysis was our assignment of patients with chronic conditions to a PCP if they had continuity for their chronic disease management and met a minimum number of visits per year for clinically adequate chronic disease management. This step allowed us to identify networks of physicians who were caring for distinct panels of patients and ensured that the PCP was reasonably able to coordinate care and communicate formally or informally about the patients identified in their panel.

PCPs who were the sole practitioners caring for patients with ACSCs had significantly lower ED utilization among

their ACSC patient panels. This implies these physicians were providing comprehensive care to these patients, which has been associated with improved health outcomes and lower health care costs.<sup>25</sup> In contrast, the narrow specialty networks available to Medicaid beneficiaries might also influence this result. Solo PCPs were more likely to be in rural or medically underserved areas; thus, limiting the PCP's connections to specialists and the availability or proximity of emergency care to rural patients.

PCPs who had a high degree of care coordination for ACSC patients and a robust specialist network available



**Figure 2.** Connected components of the patient-sharing networks of primary and specialty physicians caring for adult Medicaid beneficiaries with ambulatory care sensitive conditions with primary care continuity in Texas, 2009. Panel A: Representation of the entire network of primary care (red dots) and specialist physicians (blue dots) connected by shared patients (gray lines). Panel B: Illustration of the community detection algorithm. The algorithm partitions this component into 5 independent components (labeled by different colors).

had lower ED utilization for ACSCs in their panels. However, PCPs coordinating care for ACSC patients with many specialists did not necessarily reduce ED utilization, especially if they had a low degree of centrality, or were less influential themselves in the network or connected to less influential specialists. Formal information sharing might occur through shared electronic health records, shared patient notes, a phone call, or asynchronous messaging between providers.<sup>26,27</sup> Informal information sharing might include information shared by patients between providers or informal interactions that lead to discussions about shared patients or types of patients.<sup>28</sup> Similarly, PCPs with a high centrality, or those who had more robust opportunities to share information with influential specialists in the network, did not necessarily have lower ED utilization in their ACSC patient panels. This was especially true when PCPs had connections to a limited number of specialists. This scenario may have specific implications for physician networks caring for Medicaid beneficiaries, as specialty networks available to PCPs and beneficiaries are narrow in Medicaid plans.<sup>29-31</sup> These results show the importance of balancing the rightness-of-fit between comprehensiveness of care, robust care coordination (high centrality), and an adequate supply specialists available to Medicaid beneficiaries with chronic conditions requiring specialist consultation.

The finding that care coordination and the number of connected specialists work *together* to influence ED visits for patients with chronic ACSCs provides greater nuance to a recent study that noted 28% of ED visits were attributable

to specialists.<sup>32</sup> Additionally, our results would suggest prior findings associating higher rates of physician office visits with higher rates of multiple ED visits are incomplete without a consideration of physician-specialist networks, along with patient characteristics.<sup>33</sup> This study shows network analysis can serve as a valuable tool to measure the impact of core primary care functions like comprehensiveness of care and care coordination.

Future endeavors to improve chronic disease management should address the intersection of a PCP's centrality in the provider network and specialist connectedness together. These results are especially important in Medicaid networks, which serve a disproportionately poor, minority, and medically underserved population with high rates of chronic illness and well documented health inequities. The impact of physician participation in Medicaid networks has been linked to racial and socioeconomic health disparities in this population.<sup>34</sup> These results could inform structuring of PCP and specialist care networks to optimize health outcomes among Medicaid enrollees with chronic conditions and could potentially reduce health inequities.

This study has several limitations. First and foremost, this is a cross-sectional study on the association between PCP network characteristics and patient health outcomes (ED rates). The results of this study should not be interpreted causally, and thus this study does not serve as a prescriptive evaluation of the existing PCP networks. Nonetheless, we believe that this empirical fact is worth documenting for future research to study the underlying mechanism of PCP networks. Second, this study is restricted



**Table 3.** Results of Multivariable Regression Model Showing the Association Between the Characteristics of Care Coordination Networks of Primary Care and Specialist Physicians on the Rate of Emergency Department Visits per Patient in Primary Care Physician Chronic Ambulatory Care Sensitive Condition Patient Panels in Texas Medicaid, 2009.

| Variable                          | Definition   | Estimate | Standard error | P value |
|-----------------------------------|--|----------|----------------|---------|
| Intercept                         |  | -1.110   | 0.0311         | <.01    |
| $X_i^{Eigen}$                     | Eigenvector centrality of PCP <i>i</i> 's in the patient-sharing network   | 2.640    | 0.0475         | <.01    |
| $X_i^{Degree}$                    | The number of specialists with whom PCP <i>i</i> coordinated care  | 0.011    | 0.0002         | <.01    |
| $X_i^{Eigen} \times X_i^{Degree}$ | The interaction between PCP centrality and number of specialists with whom PCP is coordinating                     | -0.024   | 0.0004         | <.01    |
| $I_i^{Solo}$                      | PCP <i>i</i> cares for ACSC panel without specialists (binary indicator)   | -1.980   | 0.0575         | <.01    |
| $X_i^{Patients}$                  | Number of ACSC patients in PCP panel   | 0.011    | 0.0002         | <.01    |
| $X_i^{Age}$                       | The percentage of patients in PCP's panel aged 55 years and older  | 0.461    | 0.0326         | <.01    |
| $X_i^{Eci}$                       | Average Elixhauser Comorbidity Index <sup>a</sup> of patients in PCP <i>i</i> 's panel                             | -0.234   | 0.0067         | <.01    |
| $X_i^{Acs}$                       | The average number of patients with ACSC in PCP <i>i</i> 's panel  | 0.774    | 0.0105         | <.01    |
| $X_i^{MC}$                        | The percentage of patients in PCP <i>i</i> 's panel who spent more than 6 months in Medicaid managed care          | 0.629    | 0.0198         | <.01    |
| $X_i^{FFS}$                       | The percentage of patients in PCP <i>i</i> 's panel who spent more than 6 months in Medicaid fee-for-service (FFS) | -0.001   | 0.0227         | .949    |

<sup>a</sup>Elixhauser Comorbidity Index is a measure of medical complexity that predicts mortality and utilization ranging from 0 to 31, a higher number indicates higher complexity.

The chi-square tests for the overall and joint significance of Eigen, Degree, and Eigen\*Degree of this negative binomial regression model all have P values <0.01, which shows that this model is overall significant.

to Texas Medicaid patients with high primary care continuity who have a diagnosis of a chronic ACSC and may not be representative of other states or physician networks in other health care coverage plans. Beneficiaries in the sample who did not meet criteria for primary care continuity for chronic disease management of their conditions were excluded from this study. The availability of provider NPI number in only a single year of our data (2009) was a restrictive factor. Our measure of comprehensiveness does not capture involvement in care of PCPs or specialists outside the management of chronic ACSCs. This study is subject to the known limitations of analysis using claims data, which is reliant on the coding and claims submitted by providers that may be inaccurate or incomplete. Finally, physicians may have additional connections outside those included.

A natural extension of this study is to understand the mechanism behind patient-sharing network formations. This question is particularly relevant to the design and evaluation of new payment models such as accountable care organizations, which are reimbursed under pay-for-performance. Understanding how patient sharing networks differ among racial/ethnic sub-populations within Medicaid is important. Future work is needed to determine the applicability of our findings to other states and other types of health care coverage. Additionally, social network analysis only measures potential opportunities for information sharing and care coordination between PCPs and specialists. Further work is needed to understand how dyads of PCPs and

specialists interact around chronic disease management for patients with chronic ACSC.

### Conclusions

In this first of its kind social network analysis of primary care and specialty physician networks caring for Medicaid beneficiaries with ACSC, we found it is necessary to balance the role of PCP centrality in a network with the availability of specialists in the network to reduce ED utilization among patients with chronic ACSC. The right fit between primary care comprehensiveness, potential opportunities for care coordination, and adequate capacity of specialty networks is needed to drive outcomes. We also found that PCPs providing comprehensive care to patients with ACSC without specialist consultation have lower ED utilization. These findings can guide the construction of future primary and specialty provider networks. Additionally, this approach could be applied to evaluate the impact of social network effects of other groups of clinicians caring for a specific patient population. Finally, we want to emphasize that the main purpose of this study is not to evaluate the impact of existing PCP networks on ED utilization rates in PCP panels. Instead, the main contribution of this study is to show that the patient sharing patterns between PCPs and specialist clinicians can be quantified using social network analysis, and we demonstrate that this quantification can capture the impact of coordinated care on chronic disease management.

## Appendix A

Provider Taxonomies Used to Define Primary Care and Specialty Physicians.

|                               | Taxonomy   |
|-------------------------------|--|
| <b>Primary care physician</b> | General Practice, Internal Medicine, Preventive Medicine, Pediatrics or Primary Care   |
| <b>Specialty physician</b>    | Allergy and Immunology, Anesthesiology, Colon and Rectal Surgery, Dermatology, Medical Genetics, Neurological Surgery, Neuromusculoskeletal Medicine and OMM (osteopathic manipulative medicine), Neuromusculoskeletal Medicine, Sports Medicine, Nuclear Medicine, Obstetrics and Gynecology, Oncology, Ophthalmology, Optometrist, Oral and Maxillofacial Surgery, Orthopedic Surgery, Otolaryngology, Pain Medicine, Pathology, Physical Medicine and Rehabilitation, Plastic Surgery, Podiatrist, Psychiatry and Neurology, Psychologist, Surgery, Thoracic Surgery (Cardiothoracic Vascular Surgery), Transplant Surgery, Urology |

## Appendix B

International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes for Chronic Ambulatory Care Sensitive Conditions.

| Condition                                    | ICD-9-CM codes                           |
|--|--|
| <b>Convulsions</b>                           | 345, 780.3                               |
| <b>Chronic obstructive pulmonary disease</b> | 491, 492, 494, 496                       |
| <b>Asthma</b>                                | 493                                      |
| <b>Congestive heart failure</b>              | 428, 402.01, 402.11, 402.91, 518.4       |
| <b>Hypertension</b>                          | 401.0, 401.9, 402.00, 402.10, 402.90     |
| <b>Angina</b>                                | 411.1, 411.8, 413                        |
| <b>Diabetes</b>                              | 250.1, 250.2, 250.3, 250.8, 250.9, 250.0 |
| <b>Hypoglycemia</b>                          | 251.2                                    |

### Acknowledgments

We would like to acknowledge Mr Junjun Xu and Dr George Rust for their intellectual contributions to the formative stages of work.

### Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

### Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was partially supported by the National Institutes of Health, National Institute on Minority Health and Health Disparities (Grant No. P20 1P20MD006881-02), and the Research Centers in Minority Institutions (Grant No. U54 8U54MD007588).

### ORCID iD

Anne H. Gaglioti  <https://orcid.org/0000-0001-5843-8476>

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