Supplementary Materials

Section A1. Dynamic Connectedness Network Analysis

Methodologically, the connectedness network of referral behaviors is estimated using the procedure proposed by Antonakakis and his colleagues[17], and the establishment of the dynamic connectedness network is based on the forecast variance decomposition from the time-varying parameter vector autoregressive (TVP-VAR) model. Note that the TVP-VAR model specification is able to prevent the issues resulting from selecting a rolling-window size and prevent the loss of observations stemming from the rolling-window estimation process (thus preventing two major issues of the conventional dynamic connectedness network analyses estimation process[55]. Moreover, the TVP-VAR specification used to estimate the dynamic connectedness network analyses can simultaneously deal with structural change and endogeneity of providers' referral behaviors, avoiding a biased inference regarding the linkage between connectedness network relationships among providers' behaviors and quality of healthcare.

It is essential to mention that the dynamic connectedness network analysis has some advantages when compared to the conventional social network analysis. First, a recent study cast doubt on whether network indicators (such as degree, density and network ties) are able to adequately characterize healthcare providers' behaviors (such as coordinative behaviors) within a healthcare provider network.[45] The use of national ambulatory referral visits data of Taiwan's NHI system in this study (directly reflecting referral behaviors from hospitals and local clinics) can circumvent arguments against the appropriateness of network indicators to measure providers' behaviors. Second, the conventional social network analysis must first determine a threshold of shared patients in order to define a healthcare provider network. Nevertheless, there is no consensual way to define the threshold of shared patients as a marker of actual collaboration between healthcare providers.[45] Thus, we applied the national ambulatory referral visits data (belonging to aggregate time series data of Taiwan's NHI system) to bypass the need to define a provider network through an arbitrarily pre-determined threshold of shared patients. Third, the dynamic connectedness network analysis (rooted in the TVP-VAR model) is a sophisticated time series methodology that can easily accommodate the structural change and endogeneity of healthcare providers' behaviors. Specifically, we apply the same notations and model specification (used by previous study[56]) to define the pairwise directional connectedness from referral behavior *j* to referral behavior *i* as follows:

Eq (A1) $\tilde{\varphi}_{ij,t}(h) = \frac{\sum_{t=1}^{h-1}(\psi_{ij,t}^{g})^2}{\sum_{i=1}^{N}\sum_{t=1}^{h-1}(\psi_{ij,t}^{g})^2}$

Where $\tilde{\varphi}_{ij,t}^{g}(h)$ denotes the referral behavior *j*'s contribution to the referral behavior *i*'s *H*-step-ahead generalized forecast error variance decomposition at time *t*=1,2,…,*N*. $\psi_{ij,t}^{g} = S_{ij,t}^{-0.5} A_{h,t} \sum_t \varepsilon_{ij,t}$, $S_{ij,t}$ and $A_{h,t}$ are parameters matrices under a stationary TVP-VAR(1) process with time-varying volatility as follows: $y_t = \beta_t y_{t-1} + \varepsilon_t$, $\varepsilon_t \sim N(0, S_t)$, $\beta_t = \beta_{t-1} + v_t$, $v_t \sim N(0, R_t)$, and $y_t = A_t \varepsilon_{t-1} + \varepsilon_t$. $\sum_t$ represents the covariance matrix for error $\varepsilon_{ij,t}$. We further normalize $\tilde{\varphi}_{ij,t}(h)$ in terms of $\sum_{j=1}^{N}\tilde{\varphi}_{ij,t}^{g}(h) = 1$ and $\sum_{i,j=1}^{N}\tilde{\varphi}_{ij,t}^{N}(h) = N$, and the *TCI* (Total Connectedness Index) representing total interconnectedness of 16 referral behaviors within the referral behavior network is written by

Eq (A2) $\mathrm{C}_t^{g}(h) = \frac{\sum_{i,j=1,i\neq j}^{N}\tilde{\varphi}_{ij,t}^{g}(h)}{\sum_{j=1}^{N}\tilde{\varphi}_{ij,t}^{g}(h)} \times 100$

Note that *TCI* measures the total contribution of spillovers from shocks to 16 referral behaviors to the total forecast error variance. In addition, this flexible specification of equation (A2) allows us to identify the directional spillovers of the referral behavior *i* to all others *j* as follows:

Eq (A3) $\mathrm{C}_{i\to j,t}^{g}(h) = \frac{\sum_{j=1,i\neq j}^{N}\tilde{\varphi}_{ji,t}^{g}(h)}{\sum_{j=1}^{N}\tilde{\varphi}_{ji,t}^{g}(h)} \times 100$

Analogously, the directional spillovers of all other referral behaviors to the referral behavior *i* is given by

Eq (A4) $\mathrm{C}_{i\leftarrow j,t}^{g}(h) = \frac{\sum_{j=1,i\neq j}^{N}\tilde{\varphi}_{ij,t}^{g}(h)}{\sum_{j=1}^{N}\tilde{\varphi}_{ij,t}^{g}(h)} \times 100$

Note that $\mathrm{C}_{i\to j,t}^{g}(h)$ and $\mathrm{C}_{i\leftarrow j,t}^{g}(h)$ denote total directional connectedness to others and from others, respectively. Therefore, we define the Network Connectedness Index (NCI_i) of referral behavior *i* as follows:

Eq(A5) $NCI_i = [\,C^{g}_{i \to j,t}(h) + C^{g}_{i \leftarrow j,t}(h)\,] \div 2$

Note that NCI_i describes referral behavior *i's* contribution to total interconnectedness of the referral behavior network. Since *TCI* equals the sum of NCI_i ($\sum_{i=1}^{16} NCI_i$), we can further decompose *TCI* into several components as follows:

Eq(A6) $TCI = \left(\sum_i NCI_i\right)_{MC} + \left(\sum_i NCI_i\right)_{RH} + \left(\sum_i NCI_i\right)_{DH} + \left(\sum_i NCI_i\right)_{LC} = MCB + RCB + DHB + LCB$

$$= \left(\sum_i NCI_i\right)_{HRB} + \left(\sum_i NCI_i\right)_{VRB} = HRB + VRB$$

$$= \left[\left(\sum_i NCI_i\right)_{HRBH} + \left(\sum_i NCI_i\right)_{HRBL}\right] + \left[\left(\sum_i NCI_i\right)_{VRBH} + \left(\sum_i NCI_i\right)_{VRBL}\right] = HRBH + HRBL + VRBH + VRBL$$

Equation (A6) separates *TCI* into four components (*MCB, RHB, DHB, LCB*), corresponding to the contributions from interdependences of referral behaviors of medical centers (*MC*), regional hospitals (*RH*), district hospitals (*DH*), and local clinics (*LC*), respectively to the total interconnectedness of the referral behavior network. The decomposition of *TCI* in the first line of equation (A6) resembles the interdependences of referral behaviors demonstrated in Figure 1(a1)-(a4). Additionally, *TCI* also can be decomposed by two components (*HRB*, and *VRB*), corresponding to contributions from interdependences of horizontal and vertical referral behaviors, respectively, to total interconnectedness of the referral behavior network (see the second line of equation (A6)). A further decomposition of the interconnectedness of the referral behavior network contributed by interdependences of horizontal and vertical referral behaviors within the hospital sector (i.e., *HRBH* and *VRBH*) or associated with local clinics (i.e., *HRBL* and *VRBL*) is given by the third line of equation (A6). The two (four) components separated from the *TCI* in the second (third) line of equation (A6) resemble the interdependences of referral behaviors illustrated in Figure 1(b1) and (c1) (Figure 1 (b2)-(b3) and Figure 1 (c2)-(c3)), respectively. Specifically, The *TCI, HRB, HRBL, HRBH, VRB, VRBL,* and *VRBH* are computed as follows: (1) $TCI = \sum_{i=1}^{16} NCI_i$; (2) $HRB = NCI_1 + NCI_6 + NCI_{11} + NCI_{16}$; (3) $HRBL = NCI_{16}$; (4) $HRBH = HRB - HRBL$; (5) $VRB = TCI - HRB$; (6) $VRBL = NCI_4 + NCI_8 + NCI_{12} + NCI_{13} + NCI_{14} + NCI_{15}$; (7) $VRBH = VRB - VRBL$.

Section A2. Model Specification for the OLS model

The relationship between interdependences of referral behaviors on the quality of ambulatory care could be defined as follows:

Eq(A7) $PQI_t = \pi_0 + x_t'\pi_1 + z_t'\pi_2 + \xi_t$

Where, PQI_t is the hospital admissions for the ACSCs. x_t' represents a vector of the explanatory variables including the *TCI* and its decomposition to measure the interdependences of the various types of referral behaviors. z_t' denotes a vector of the control variables, such as demographic structure and income level. π_i and ξ_t are parameters and error term, respectively. The first order of difference of all variables was taken before estimating the equation (A7) in order to prevent spurious correlation between dependent variable (PQI_t) and independent variables (x_t' , and z_t') from the nature of the unit root property involved in time series data. The Ordinary Least Square (OLS) method was first used to estimate the equation (A7) but the robust t-statistics in the equation (A7) were calculated using the estimated coefficients divided by the Newey-West standard errors in order to avoid a potential serial-correlation bias from the OLS estimation. These same methods to deal with serial-correlation bias from the OLS estimation has been previously suggested by Chen and his colleagues.[46]

Section A3. Connectedness Network Analysis

(a)Unit Root Tests for Referral Behaviors

Table A1 summarizes the descriptive statistics and the PP unit root tests of weekly aggregate ambulatory referral visits corresponding to 16 referral behaviors generated from local clinics, district hospitals, regional hospitals and medical centers under Taiwan's NHI system (see Figure 1 (a1)-(a4) and assign 16 corresponding referral behavior codes, i.e., RBC_i , i=1,2,..,16). As indicated by Table A1, there are four main groups of 16 referral behaviors: *the first being* referral behaviors from medical centers (such as ambulatory care referrals between medical centers (RBC_1) and ambulatory care referrals from medical centers to regional hospitals (RBC_2), district hospitals (RBC_3) and local clinics (RBC_4)), *the second being* referral behaviors from regional hospitals (such as ambulatory care referrals between regional hospitals

(RBC_6) and ambulatory care referrals from regional hospitals to medical centers (RBC_5), district hospitals (RBC_7) and local clinics (RBC_8)), *the third being* referral behaviors from district hospitals (such as ambulatory care referrals between district hospitals (RBC_{11}) and ambulatory care referrals from district hospitals to medical centers (RBC_9), regional hospitals (RBC_{10}) and local clinics (RBC_{12})), and *the fourth being* referral behaviors from local clinics (such as ambulatory care referrals between local clinics (RBC_{16}) and ambulatory care referrals from local clinics to medical centers (RBC_{13}), regional hospitals (RBC_{14}) and district hospitals (RBC_{15})). The time plots of these 16 weekly time series of ambulatory referral visits in Figure A1 demonstrate either linear or cyclical trends, and no matter which demean or de-trend data is used for the PP unit root tests[54], the null hypotheses of unit root of time series are rejected at 5% (or rigorous) significance level. These results validate the application of the TVP-VAR-based connectedness network analyses for these 16 weekly time series of ambulatory referral visits.

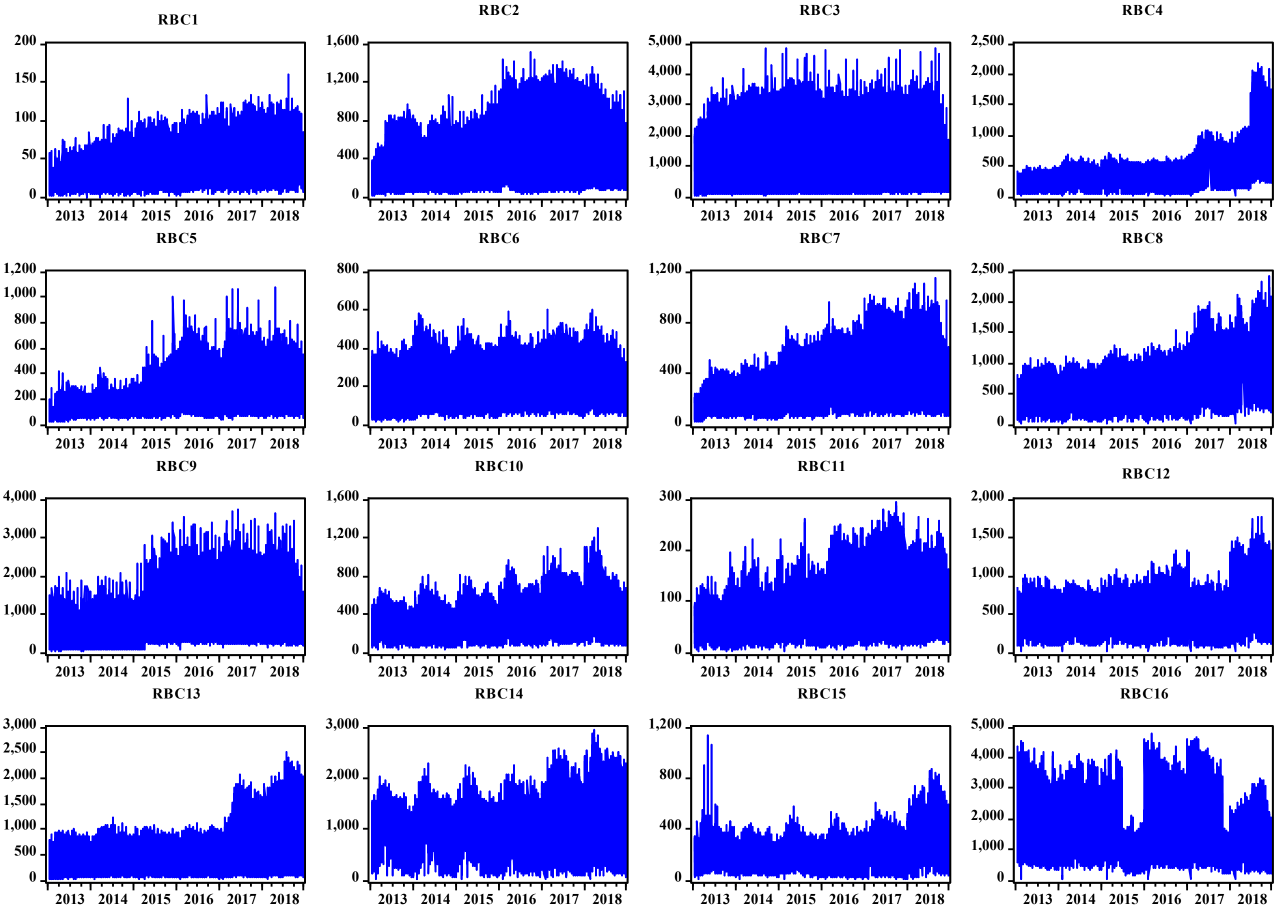


Figure A1 Ambulatory Referral Visits by Individual Referral Behavior (Weekly Aggregate)

Table A1 Descriptive Statistics and Unit Root Tests for Ambulatory Care Referrals (Visits)†

Referral Behaviors of Care Providers		Descriptive Statistics				PP Unit Root Test	
Behavior Codes	Description	Mean	SD	Max	Min	Constant	Constant & Trend
RBC1	Ambulatory care referrals between medical centers	398.22	104.44	591	115	**-7.42**	**-15.84**
RBC2	Ambulatory care referrals from medical centers to regional hospitals	4275.55	1043.41	6037	1429	**-5.65**	**-9.20**
RHC3	Ambulatory care referrals from medical centers to district hospitals	15695.64	2351.97	20903	5461	**-13.64**	**-13.87**
RBC4	Ambulatory care referrals from medical centers to local clinics	3566.08	1911.39	10146	801	**-3.07**	**-8.37**
RBC5	Ambulatory care referrals from regional hospitals to medical centers	2373.59	951.88	4036	495	**-3.09**	**-6.92**
RBC6	Ambulatory care referrals between district hospitals	2019.54	280.57	2781	832	**-14.15**	**-14.46**
RBC7	Ambulatory care referrals from regional hospitals to district hospitals	2948.10	1020.34	5119	539	**-4.05**	**-11.67**
RBC8	Ambulatory care referrals from regional hospitals to local clinics	6056.83	1906.32	10701	1287	**-6.62**	**-13.10**
RBC9	Ambulatory care referrals from district hospitals to medical centers	10884.93	3239.34	17159	2063	**-5.84**	**-10.02**
RBC10	Ambulatory care referrals from district hospitals to regional hospitals	3191.28	800.24	5362	896	**-8.61**	**-11.08**
RBC11	Ambulatory care referrals between district hospitals	834.69	255.04	1334	226	**-4.71**	**-9.12**
RBC12	Ambulatory care referrals from district hospitals to local clinics	4930.87	1146.52	8365	1041	**-10.28**	**-12.19**
RBC13	Ambulatory care referrals from local clinics to medical centers	5781.04	2326.18	12104	1301	**-4.61**	**-9.50**
RBC14	Ambulatory care referrals from local clinics to regional hospitals	9334.99	2069.05	14147	2055	**-10.10**	**-10.94**
RBC15	Ambulatory care referrals from local clinics to district hospitals	2139.06	672.33	4233	500	**-7.09**	**-8.95**
RBC16	Ambulatory care referrals between local clinics	6690.27	4421.69	25789	3336	**-6.79**	**-7.19**

† Weekly data were collected from January 1st 2013 to December 31st 2018, resulting in a total of 313 weekly observations. Data were transformed into natural logarithms for the unit root tests. Bold fonts represent 5% (or rigorous) significance levels.

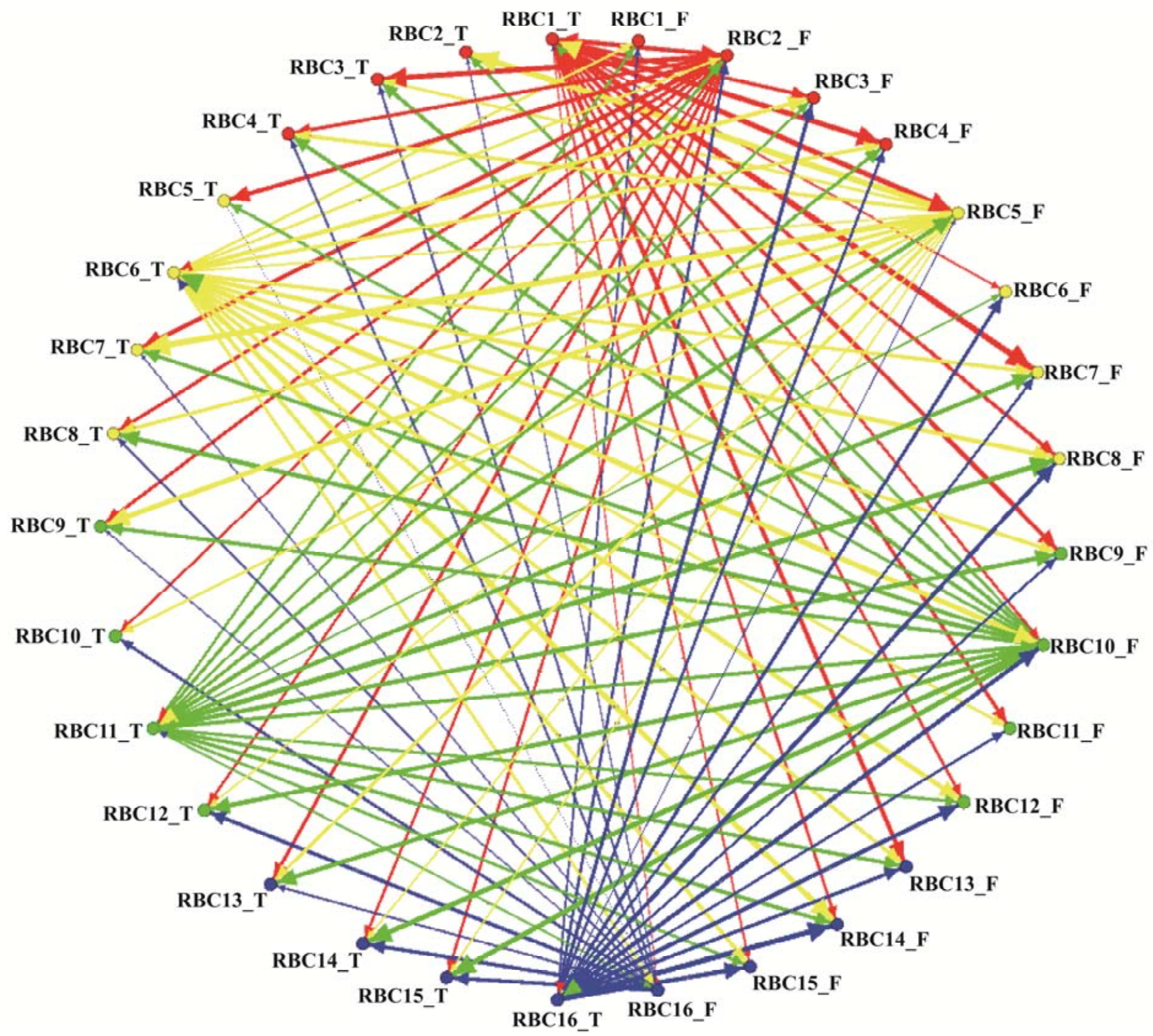
(b) Static Connectedness Network Analysis

Table A2 is the *static* connectedness network matrix for 16 weekly time series of ambulatory referral visits based on the methodology proposed by Antonakakis and his colleagues.[17] The ij^{th} element of the matrix shows the estimated contribution to the forecast error variance of the i^{th} time series of ambulatory referral visits from shocks to the j^{th} time series of ambulatory referral visits, as specified in equation (A1). Accordingly, the off-diagonal sum of elements in each row presents the directional spillovers from all other time series of ambulatory referral visits to the i^{th} time series of ambulatory referral visits, and the off-diagonal sum of elements in each column presents the directional spillovers to all other time series of ambulatory referral visits from the j^{th} time series of ambulatory referral visits, as showed in equations (A3)-(A4). As shown in Table 1, the *TCI* is 88.60%, suggesting approximately 88.60% of the total forecast error variance could be explained by the spillovers from shocks to these 16 weekly time series of ambulatory referral visits, corresponding to Figure A2 (c1). The results for the NCI_i from the i^{th} time series of ambulatory referral visits (NCI_i in the bottom of Table A2) show that the interconnectedness of the referral behavior network contributed by the vertical referral behaviors (*VRB*) represents 77.70% (=68.4/88.6) of *TCI*, three times higher than that contributed by the horizontal referral behaviors (*HRB*), corresponding to Figure A2 (a1)-(b1). The interconnectedness of the referral behavior network contributed by the horizontal referral behaviors within the hospital sector (*HRBH*) is also three times higher than that contributed by the horizontal referral behaviors within local clinics (*HRBL*), corresponding to Figure A2 (a2)-(a3). The interconnectedness of the referral behavior network contributed by the vertical referral behaviors within the hospital sector (*VRBH*) is roughly the same as that contributed by the vertical referral behaviors associated with local clinics (*VRBL*), corresponding to Figure A2 (b2)-(b3).

Table A2 Static Connectedness Network for 16 Referral Behaviors †

	RBC1	*RBC2*	*RBC3*	*RBC4*	*RBC5*	*RBC6*	*RBC7*	*RBC8*	*RBC9*	*RBC10*	*RBC11*	*RBC12*	*RBC13*	*RBC14*	*RBC15*	*RBC16*	Contribution from others (B)
RBC1	11.3	6.7	5.5	7.5	7.5	4.3	8.7	6.3	7.1	5.2	5.7	4.6	7.4	5.1	4.4	2.9	88.7
RBC2	6.9	12.4	6.0	6.0	8.6	3.7	9.0	6.2	6.2	5.4	4.8	4.4	6.9	4.9	5.3	3.2	87.6
RBC3	6.7	7.7	9.5	5.2	4.9	5.8	7.1	6.3	/7.1	6.0	5.0	6.0	6.5	6.5	5.5	4.2	90.5
RBC4	5.5	5.6	4.2	11.7	6.3	4.1	7.4	8.0	6.0	6.1	6.2	5.7	8.2	5.6	5.6	3.8	88.3
RBC5	6.7	7.0	3.9	6.8	14.9	3.4	10.1	6.4	8.9	5.3	6.1	3.9	6.4	4.4	4.1	1.8	85.1
RBC6	5.2	5.2	6.9	5.5	4.0	10.9	6.3	6.7	5.7	7.5	5.1	6.6	6.0	7.6	5.6	5.2	89.1
RBC7	6.9	6.9	4.8	7.2	9.0	4.0	11.2	6.8	7.1	6.2	5.6	4.6	6.9	5.2	4.9	2.8	88.8
RBC8	4.9	5.8	5.0	7.3	5.6	4.5	7.1	9.2	6.3	6.9	6.3	6.6	7.1	6.9	6.2	4.4	90.8
RBC9	6.0	6.2	6.4	5.7	8.2	4.3	8.3	6.9	11.5	5.9	6.6	5.3	5.9	5.3	4.6	3.1	88.5
RBC10	4.5	5.2	5.1	5.9	4.8	5.7	6.9	7.9	5.9	9.6	5.9	6.8	6.2	8.1	6.4	5.1	90.4
RBC11	4.7	5.6	4.8	6.2	7.0	4.4	7.4	7.7	7.4	6.0	13.5	5.2	5.8	5.7	5.0	3.5	86.5
RBC12	4.4	4.9	5.9	6.0	3.9	5.5	5.6	8.3	5.7	7.4	5.2	10.3	6.5	8.0	6.9	5.6	89.7
RBC13	5.7	5.7	5.0	8.4	5.6	4.5	6.8	7.9	5.6	6.6	5.4	6.0	9.9	6.7	6.4	4.0	90.1
RBC14	4.7	4.7	5.7	5.5	3.6	6.0	5.9	8.0	5.2	8.4	5.2	7.6	6.6	9.7	7.4	5.9	90.3
RBC15	4.1	5.3	5.2	6.1	4.0	4.7	5.7	7.9	4.9	7.6	5.3	7.0	6.9	8.7	11.1	5.6	88.9
RBC16	4.1	5.0	5.8	5.1	3.0	5.7	4.8	6.8	4.8	7.3	4.6	7.2	5.7	8.1	6.5	15.5	84.5
Contribution to others (A)	81.0	87.3	80.2	94.4	86.1	70.6	107.1	107.9	94.0	97.9	82.8	87.4	98.9	96.7	84.5	61.1	1417.9
NCI_i (A+B/2/16)	5.3	5.5	5.3	5.7	5.4	5.0	6.1	6.2	5.7	5.9	5.3	5.5	5.9	5.8	5.4	4.6	*TCI*=88.6
Competition by Behaviors	*HRB*=20.2								*VRB*=68.4								*TCI*=88.6
Competition by Behavior & Sectors	*HRBH*=15.6				*HRBL*=4.6				*VRBH*=33.9				*VRBL*=34.5				*TCI*=88.6

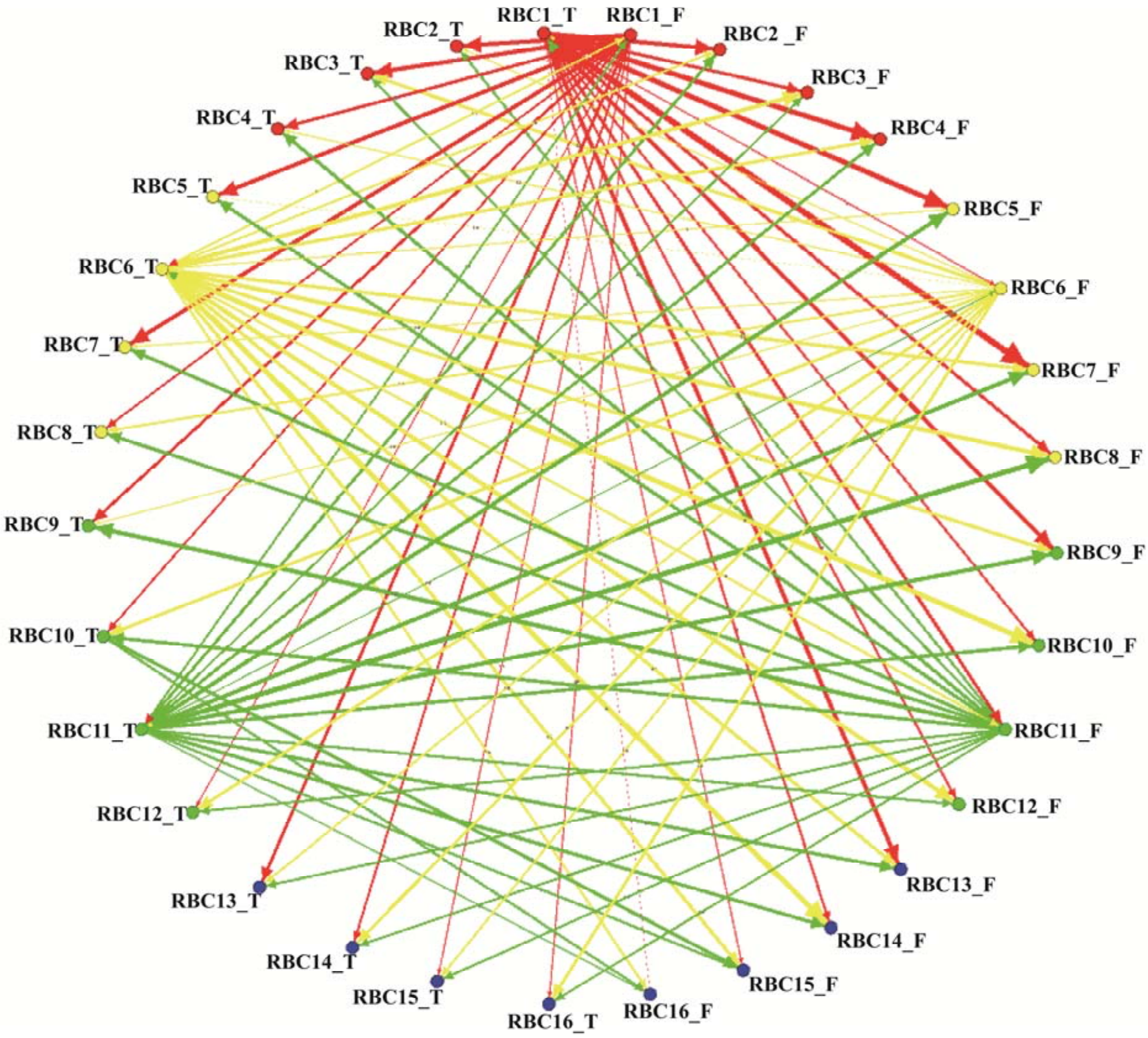
† The percentage (%) of contribution to the forecast error variance of ambulatory referral visits on the referral behavior code *RBC i* coming from that on *RBC j* using the Time-varying Parameters (TVP) VAR model. The row titled "Contribution to others" ("Contribution from others") shows of % of contribution of each *RBC* (except the given *RBC*) to (from) all others. Network Connectedness Index (NCI_i) from the referral behavior *i* measures interconnectedness of the network of referral behavior *i*. *HRB*, *VRB*, *HRBH*, *VRBH*, *HRBL*, and *VRBL* measures interconnectedness of the network of referral behaviors defined by equation (A6).



(a1) *HRB*

Figure A2：Connectedness of Referral Behavior Network (a1)

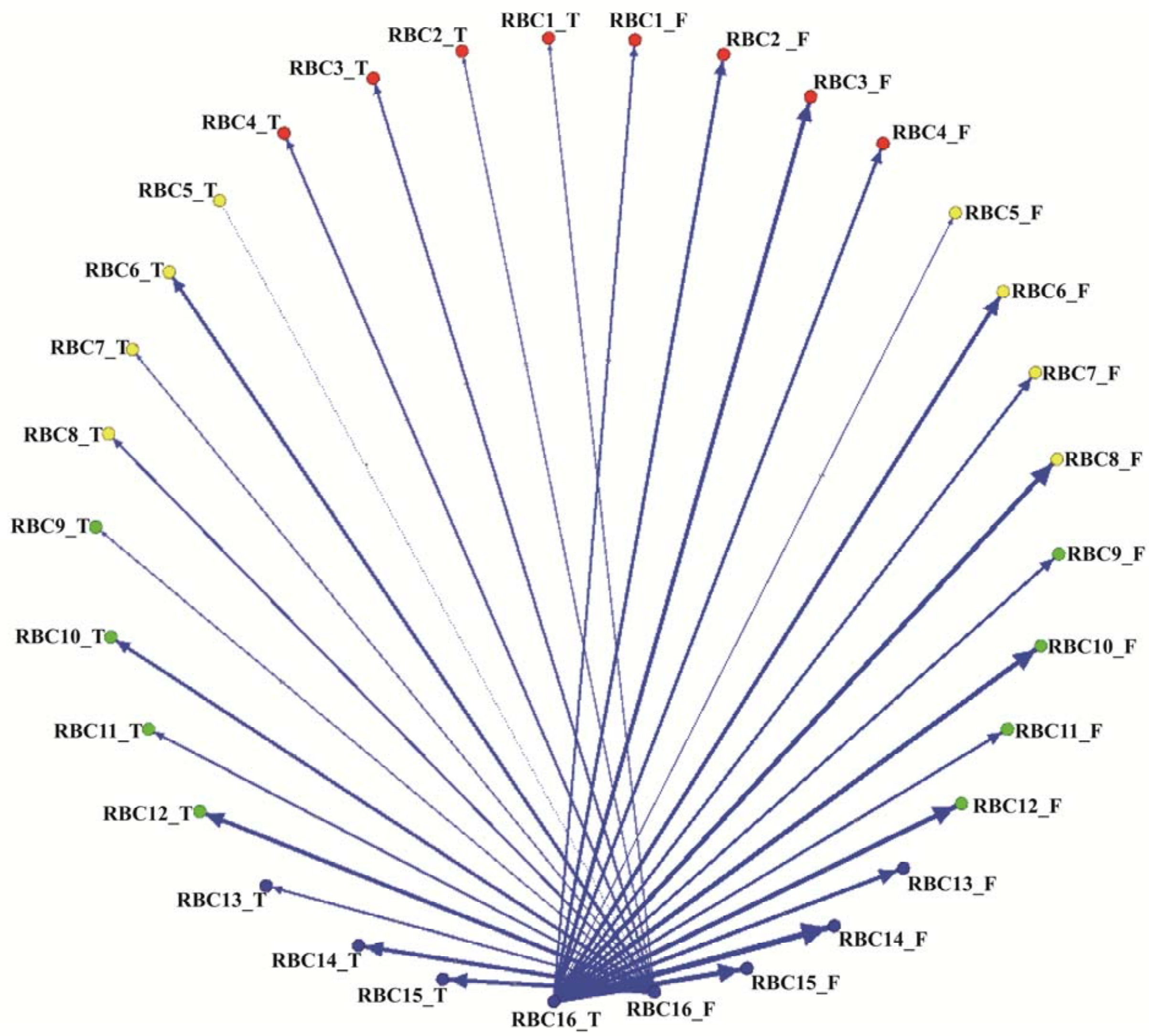
Note: The *HRB, HRBH, HRBL, VRB, VRBH, VRBL,* and *TCI* are defined in the same manner as shown in Table 1 of maintext. *RBCi_T* and *RBCi_F* (*i*=1,2,…,16) represent directional connectedness to others and from others for each referral behavior, respectively Red, yellow, green, and blue lines represents the referral behavior connectedness from medical centers, regional hospitals, district hospitals, and local clinics, respectively.



(a2) *HRBH*

Figure A2：Connectedness of Referral Behavior Network (a2)

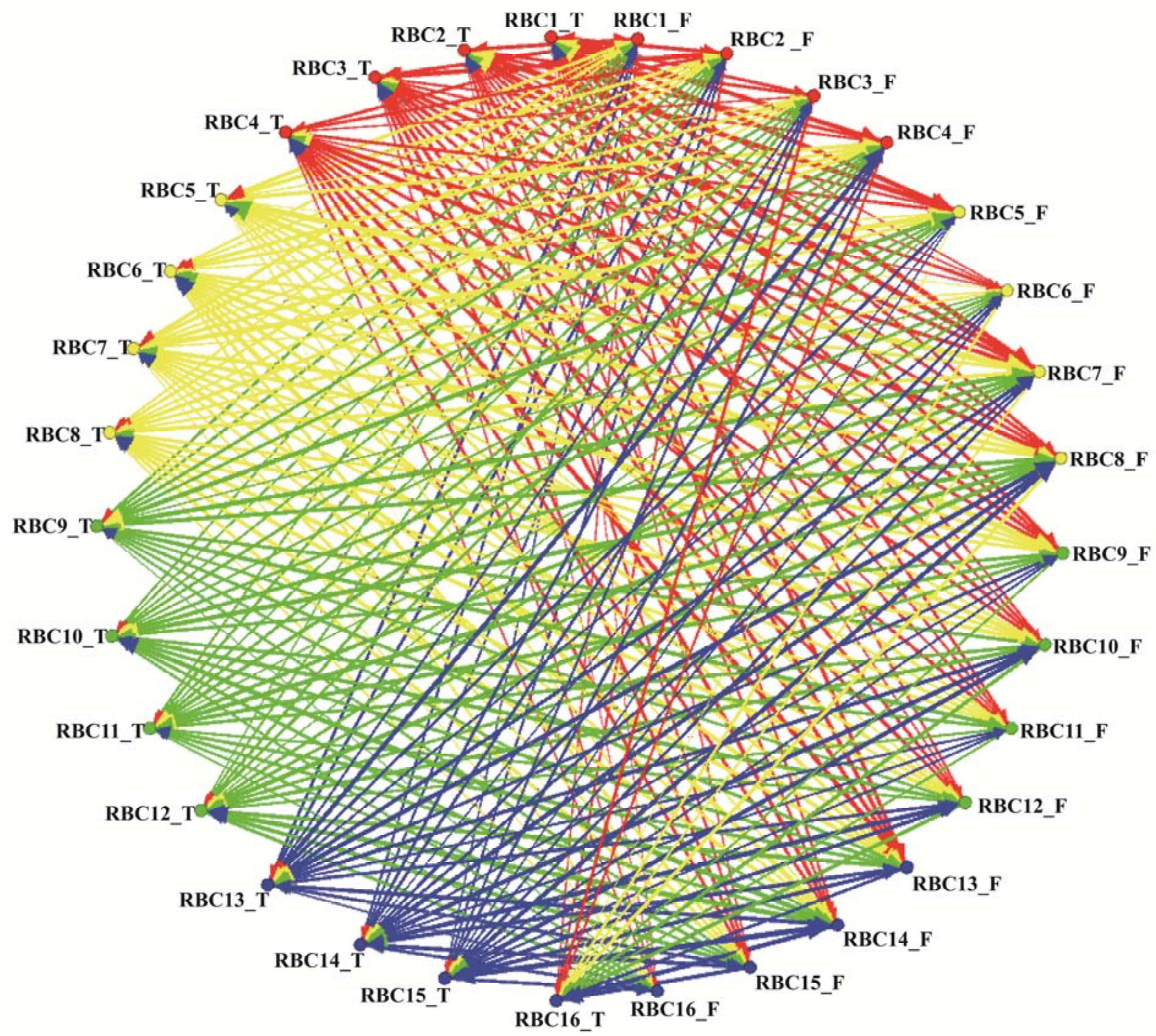
Note: The *HRB, HRBH, HRBL, VRB, VRBH, VRBL*, and *TCI* are defined in the same manner as shown in Table 1 of maintext. *RBCi_T* and *RBCi_F* (*i*=1,2,…16) represent directional connectedness to others and from others for each referral behavior, respectively Red, yellow, green, and blue lines represents the referral behavior connectedness from medical centers, regional hospitals, district hospitals, and local clinics, respectively.



(a3) *HRBL*

Figure A2：Connectedness of Referral Behavior Network (a3)

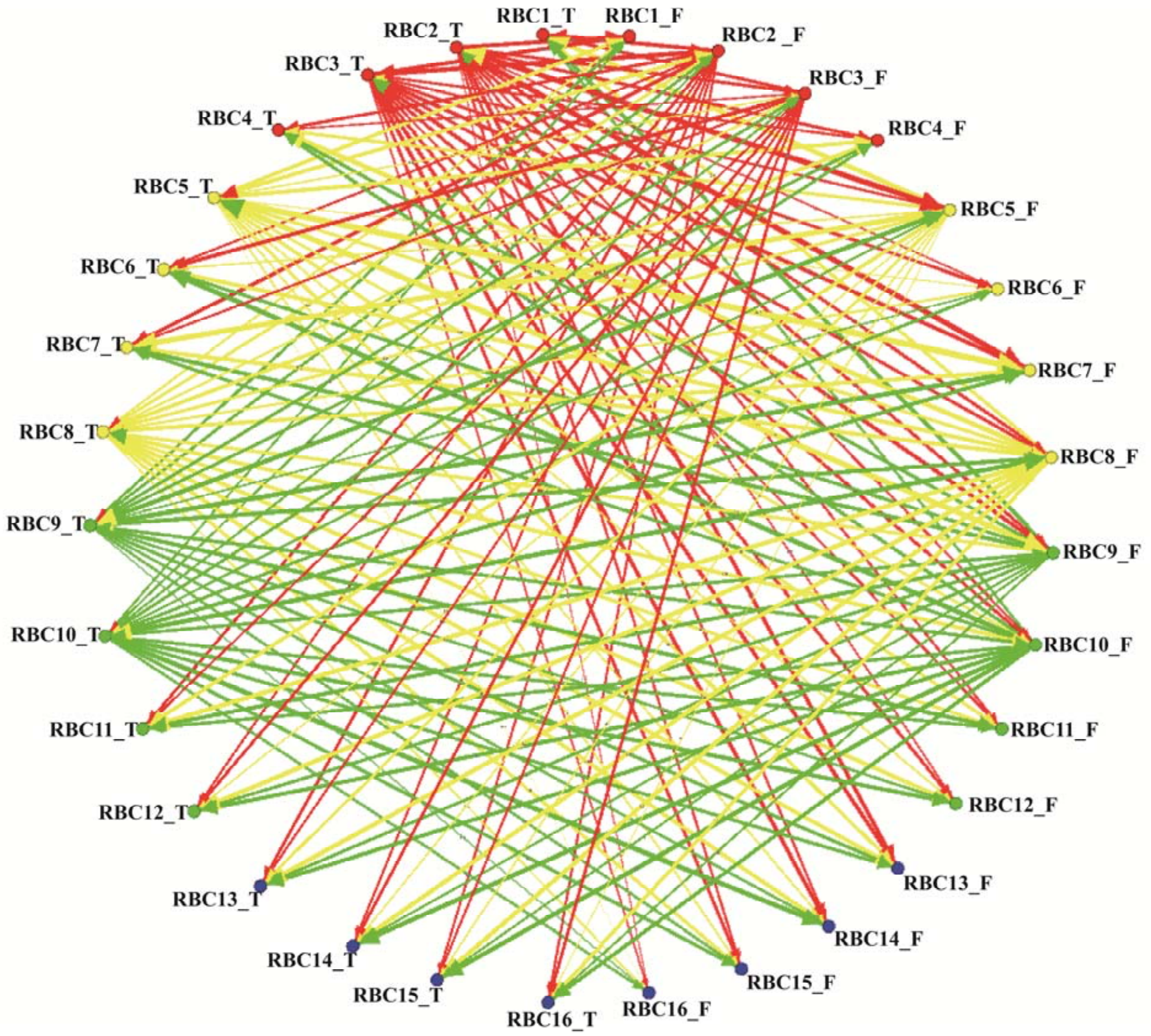
Note: The *HRB, HRBH, HRBL, VRB, VRBH, VRBL,* and *TCI* are defined in the same manner as shown in Table 1 of maintext. *RBCi_T* and RBCi_F (*i*=1,2,…16) represent directional connectedness to others and from others for each referral behavior, respectively Red, yellow, green, and blue lines represents the referral behavior connectedness from medical centers, regional hospitals, district hospitals, and local clinics, respectively.



(b1) *VRB*

Figure A2：Connectedness of Referral Behavior Network (b1)

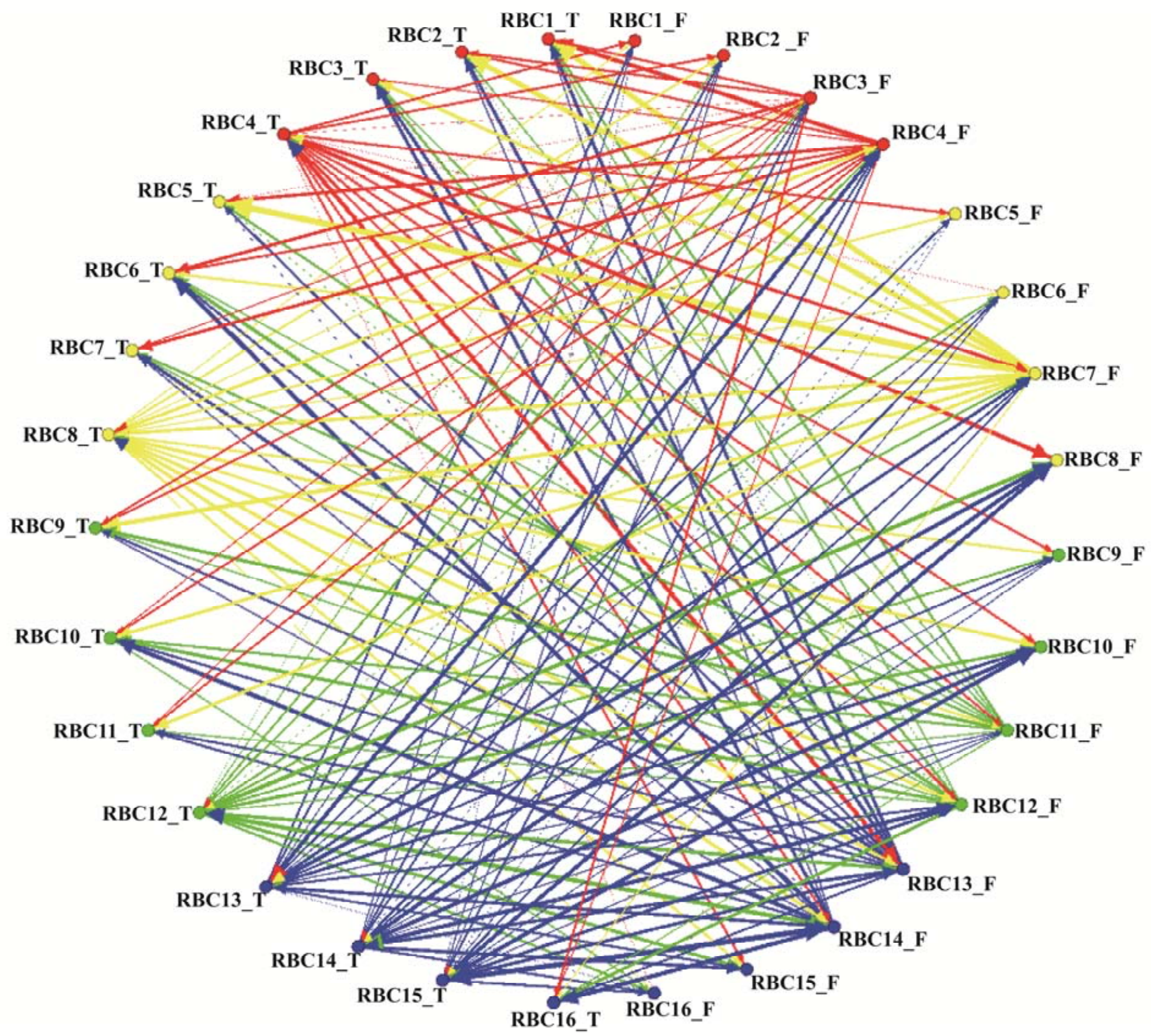
Note: The *HRB, HRBH, HRBL, VRB, VRBH, VRBL,* and *TCI* are defined in the same manner as shown in Table 1 of maintext. *RBCi_T* and *RBCi_F* (*i*=1,2,…16) represent directional connectedness to others and from others for each referral behavior, respectively Red, yellow, green, and blue lines represents the referral behavior connectedness from medical centers, regional hospitals, district hospitals, and local clinics, respectively.



(b2) *VRBH*

Figure A2：Connectedness of Referral Behavior Network (b2)

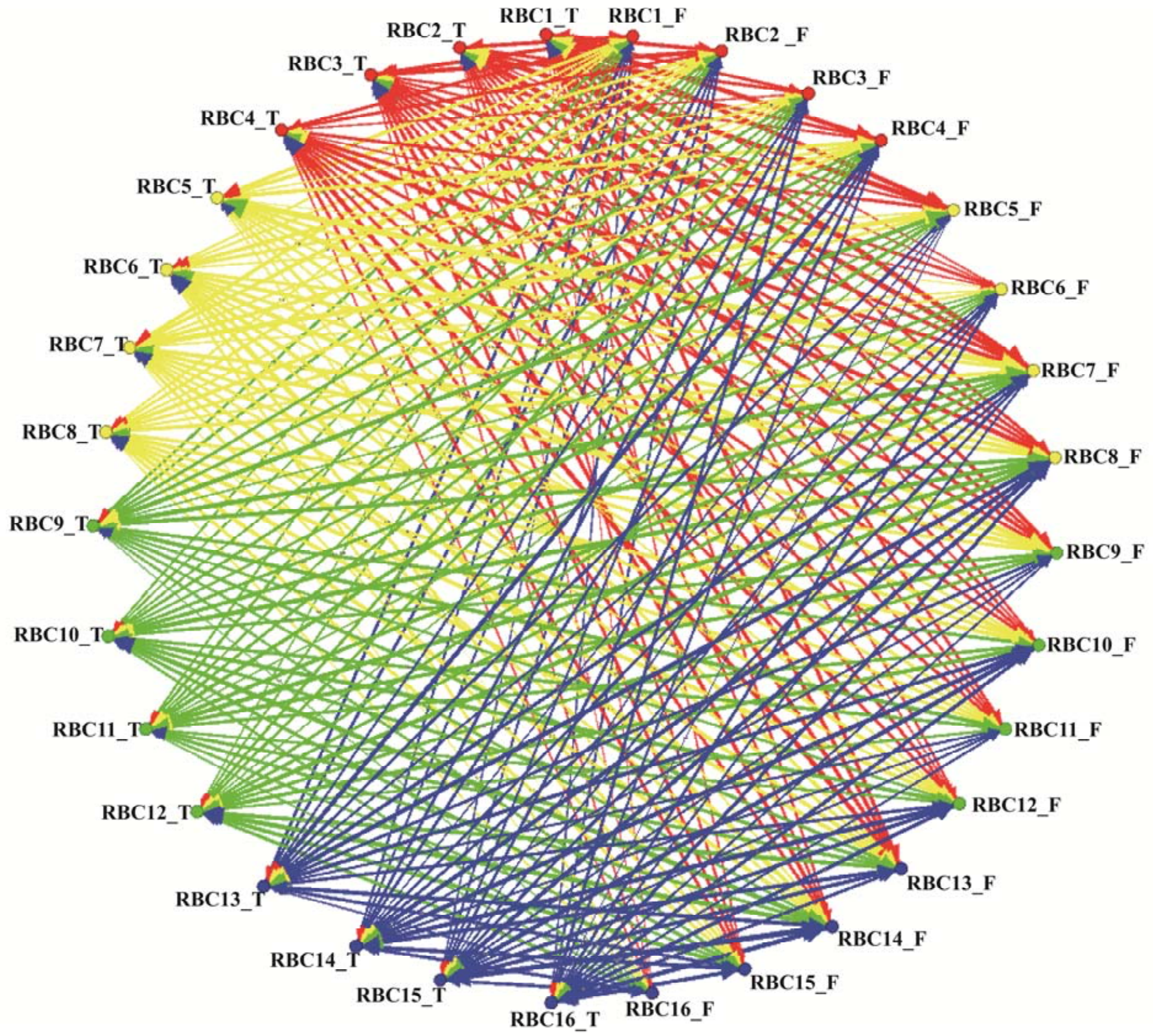
Note: The *HRB, HRBH, HRBL, VRB, VRBH, VRBL,* and *TCI* are defined in the same manner as shown in Table 1 of maintext. *RBCi_T* and *RBCi_F* (*i*=1,2,…16) represent directional connectedness to others and from others for each referral behavior, respectively Red, yellow, green, and blue lines represents the referral behavior connectedness from medical centers, regional hospitals, district hospitals, and local clinics, respectively.



(b3) *VRBL*

Figure A2：Connectedness of Referral Behavior Network (b3)

Note: The *HRB, HRBH, HRBL, VRB, VRBH, VRBL,* and *TCI* are defined in the same manner as shown in Table 1 of maintext. *RBCi_T* and *RBCi_F (i*=1,2,…,16) represent directional connectedness to others and from others for each referral behavior, respectively Red, yellow, green, and blue lines represents the referral behavior connectedness from medical centers, regional hospitals, district hospitals, and local clinics, respectively.



(c1) *TCI*

Figure A2：Connectedness of Referral Behavior Network (c1)

Note: The *HRB, HRBH, HRBL, VRB, VRBH, VRBL,* and *TCI* are defined in the same manner as shown in Table 1 of maintext. RBC_i_T and RBC_i_F (i=1,2,…,16) represent directional connectedness to others and from others for each referral behavior, respectively Red, yellow, green, and blue lines represents the referral behavior connectedness from medical centers, regional hospitals, district hospitals, and local clinics, respectively.

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