High-Speed Rail Network Structure and Implications for Air Transport: The Case of Northeast Asia

Shuli Liu, Yulai Wan, Yuichiro Yoshida, Anming Zhang, and Hun-Koo Ha

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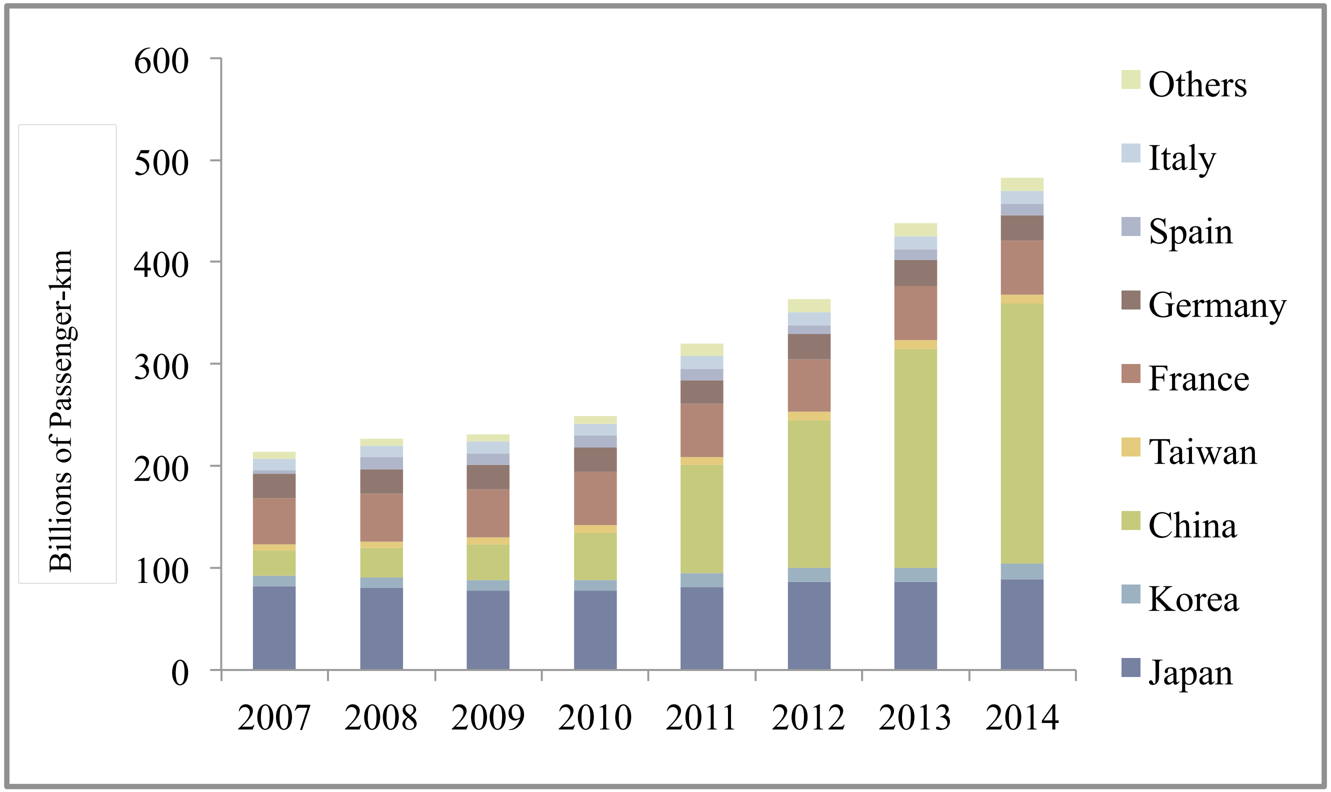
Introduction



Development of High-speed Rail Traffic (2007-2014) *Source*: UIC

Introduction

- The big question: How does HSR affect air transport?

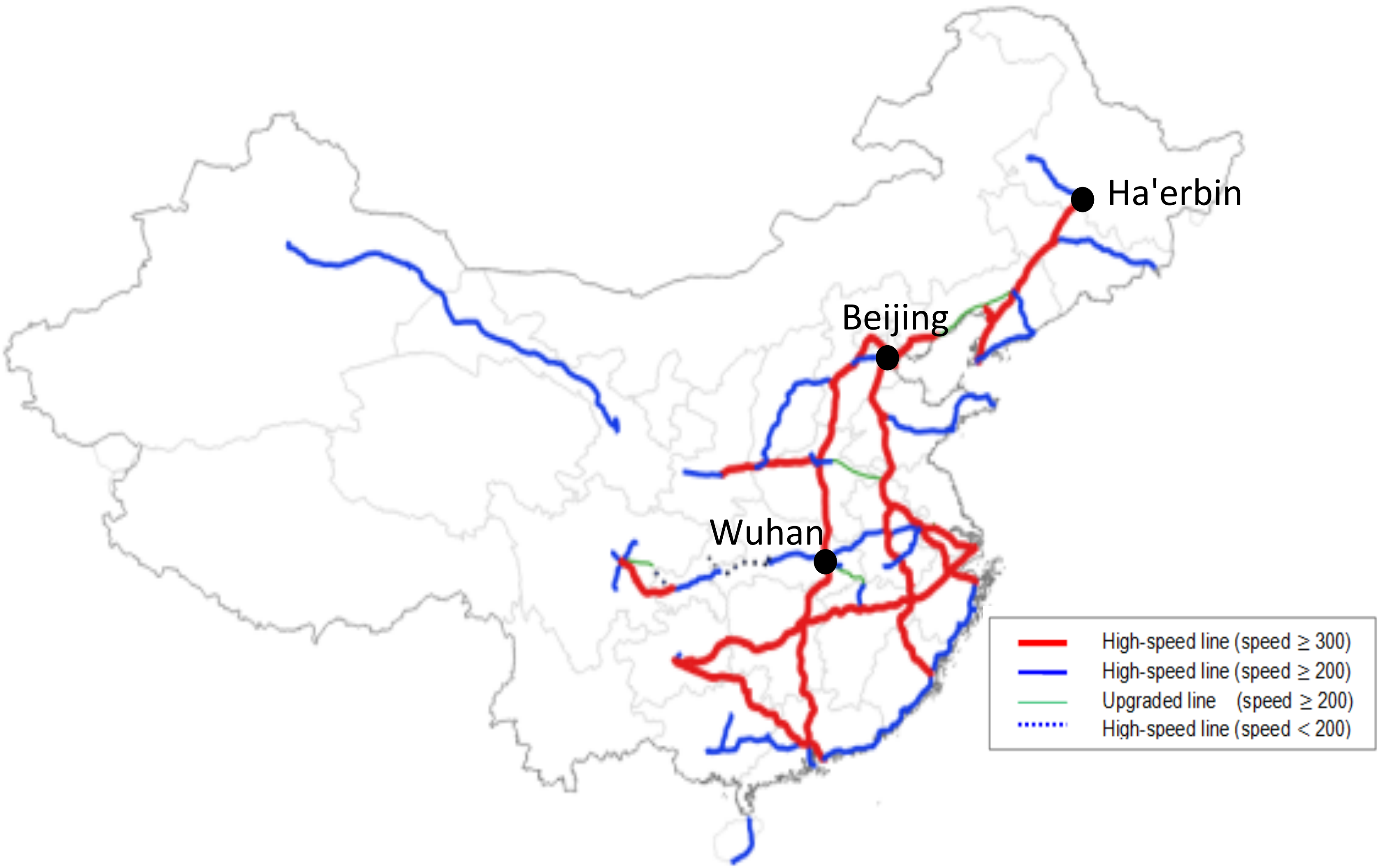
- Empirical studies in the literature
  - Mainly at route level (see a review by Wan et al, 2016)
  - Substitution effect
  - Explanatory variables: availability of HSR services, travel time, travel cost, frequency, etc.

- Limited airport level study (Castillo-Manzano et al., 2015)
  - Impact on airport passenger number
  - Expansion of HSR network measured by the system-wide HSR passenger number

Why airport level is important?

- HSR may release slots occupied by short-haul flights and mitigate airport congestion (Jiang and Zhang, 2014)
- But the net traffic impact is unclear
  - Traffic of some affected long-haul routes may increase (Wan et al, 2016)
  - Expansion of catchment (complementary effect)
  - Air-HSR integration may increase traffic on other routes (Jiang and Zhang, 2014; Xia and Zhang, 2017)
  - Airlines may be forced to develop new routes, e.g. international routes, and re-organize network to hub-and-spoke network (Jiang and Zhang, 2016)
- Unclear impact on airport efficiency
- **Other issues missing in the literature**
  - **Position of the airport in the HSR network**
  - **Network of HSR services versus network of HSR infrastructure**

China HSR network 2015



Location affects the importance of the city in the HSR network.

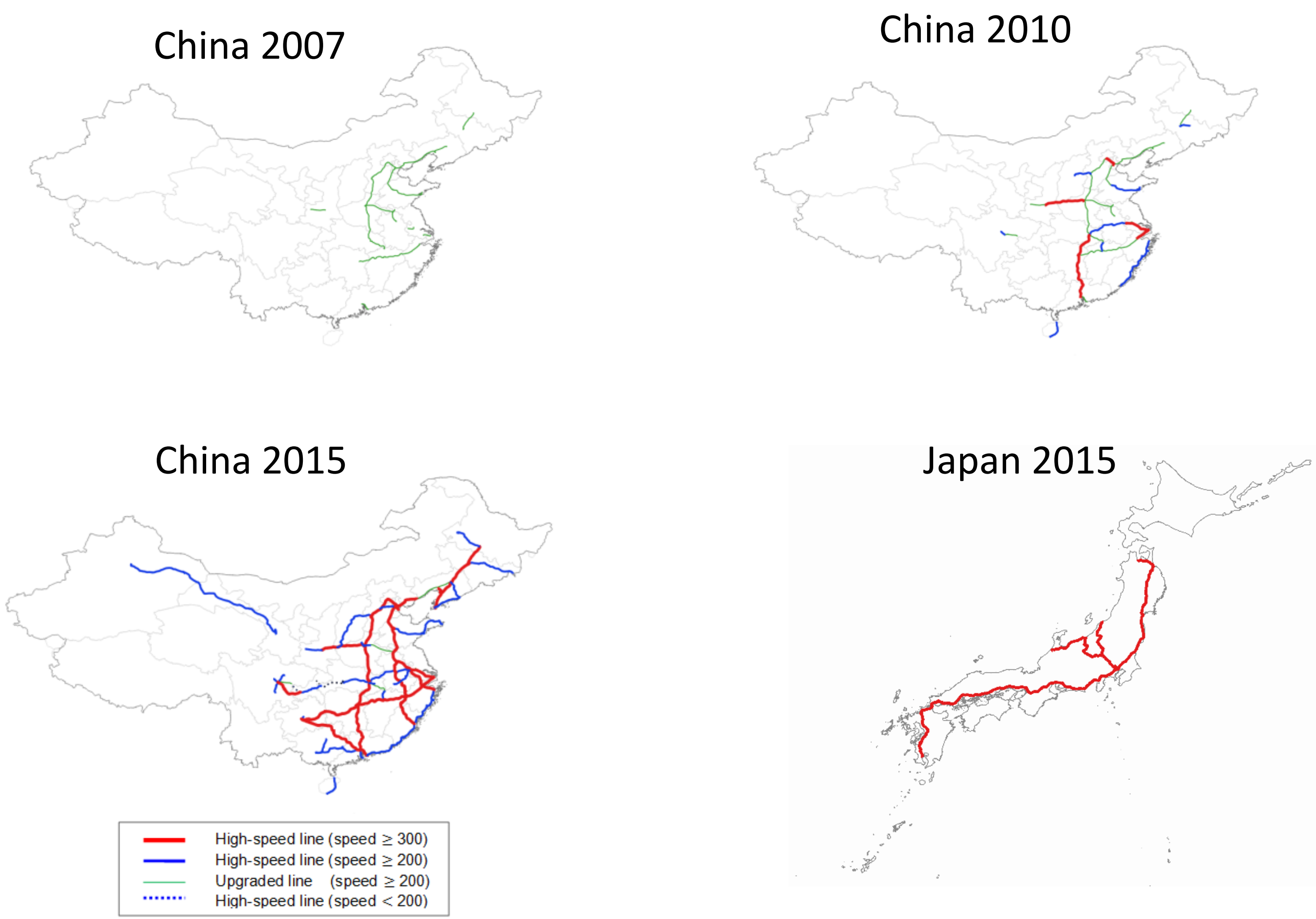
Research question

- How to appropriately measure the position (importance) of a city in HSR network?
- How does the position of the airport city in the HSR network influence airport traffic and efficiency?

- Measure both substitution effect and complementary effect of HSR on airport

- Compare China and Japan
  - Different development stages
  - Different network structures

HSR network structure: China vs. Japan

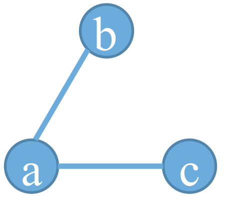


“Importance” of a node in the HSR network

- Apply the concept of *centrality* in complex network theory to measure node importance

- Degree (Freeman, 1979): A measure of connectivity
  - The number of nodes directly connected to node i

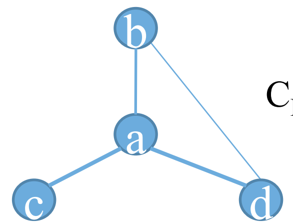
$$C_D(i) = \sum_{j=1}^{n} a_{ij}$$



$C_D(a) = 2$

- Betweenness (Freeman, 1977): Measure the potential of becoming a transit point

$$C_B(i) = \sum_{i \neq j \neq k} \frac{\sigma_{jk}(i)}{\sigma_{jk}}$$



$C_B(a) = 1/1 + 0/1 + 1/1 = 2$

  - Where $\sigma_{jk}(i)$ = the number of shortest paths between nodes j and k that pass through node i; σ_{jk} = the total number of shortest paths between nodes j and k

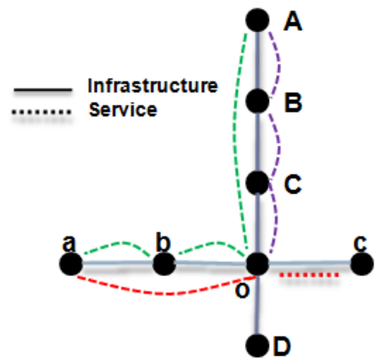
- Harmonic (Dekker, 2005; Rochat, 2009): Reflect closeness of a node to the other nodes
  - Sum of the inversed shortest distance between node i and the other nodes

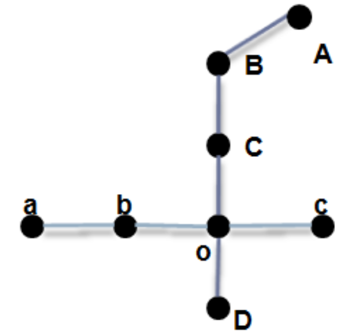
$$C_H(i) = \sum_{i \neq j} \frac{1}{d(i, j)}$$

- "Length" of a path or distance is measured by the designed travel time for infrastructure network and generalized travel cost for service network
  - Designed travel time = distance / design speed
  - Generalized travel cost = ticket price + scheduled travel time * hourly wage

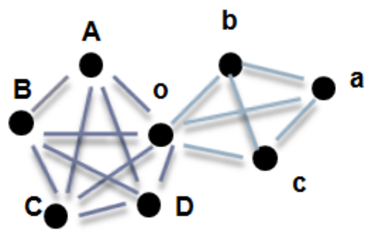
Three topologies to represent rail networks (Kurant and Thiran, 2006)

- L-space: Two nodes (stations) are connected only if they are physically directly connected by the infrastructure (with no station in between)
- P-space: Any two nodes on the same infrastructure line are considered as connected
- Service: Two nodes are considered as connected if they are linked by the same train service, regardless the infrastructure used

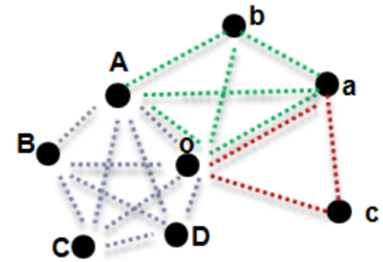




L-space Infrastructure Structure

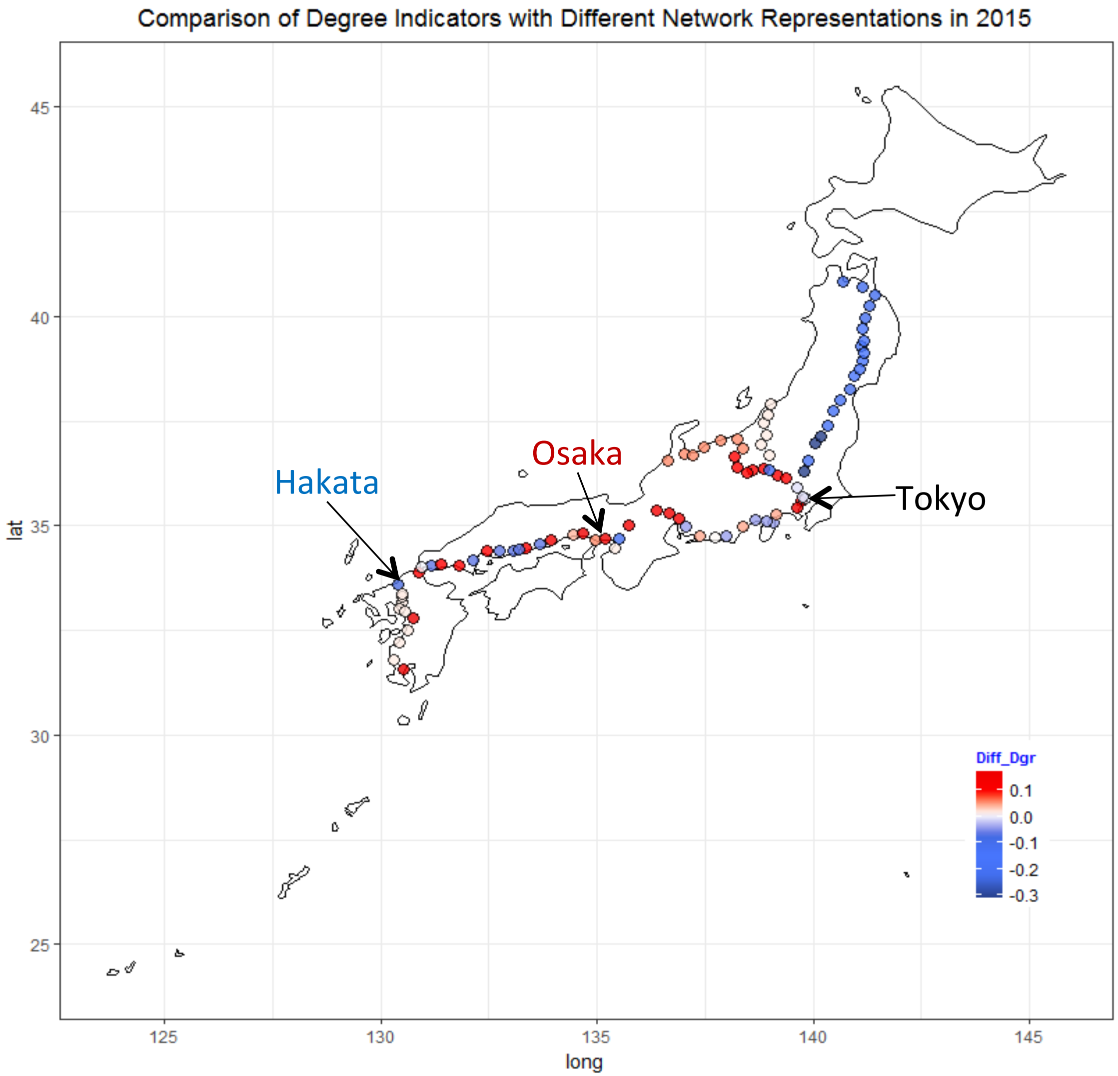


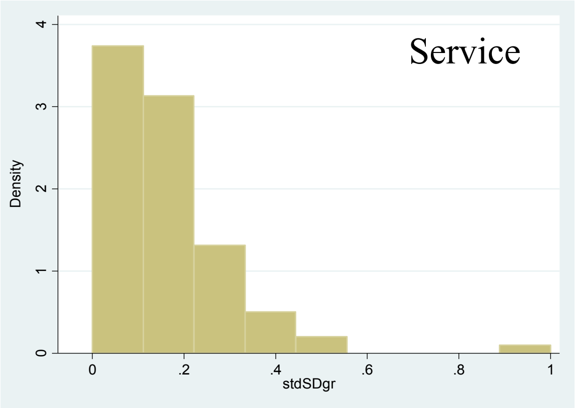
P-space Infrastructure Structure

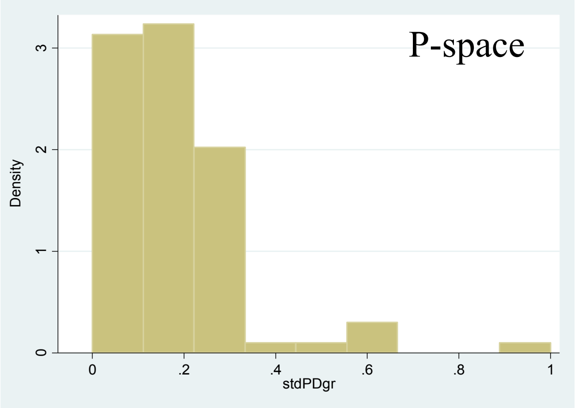


Service Structure

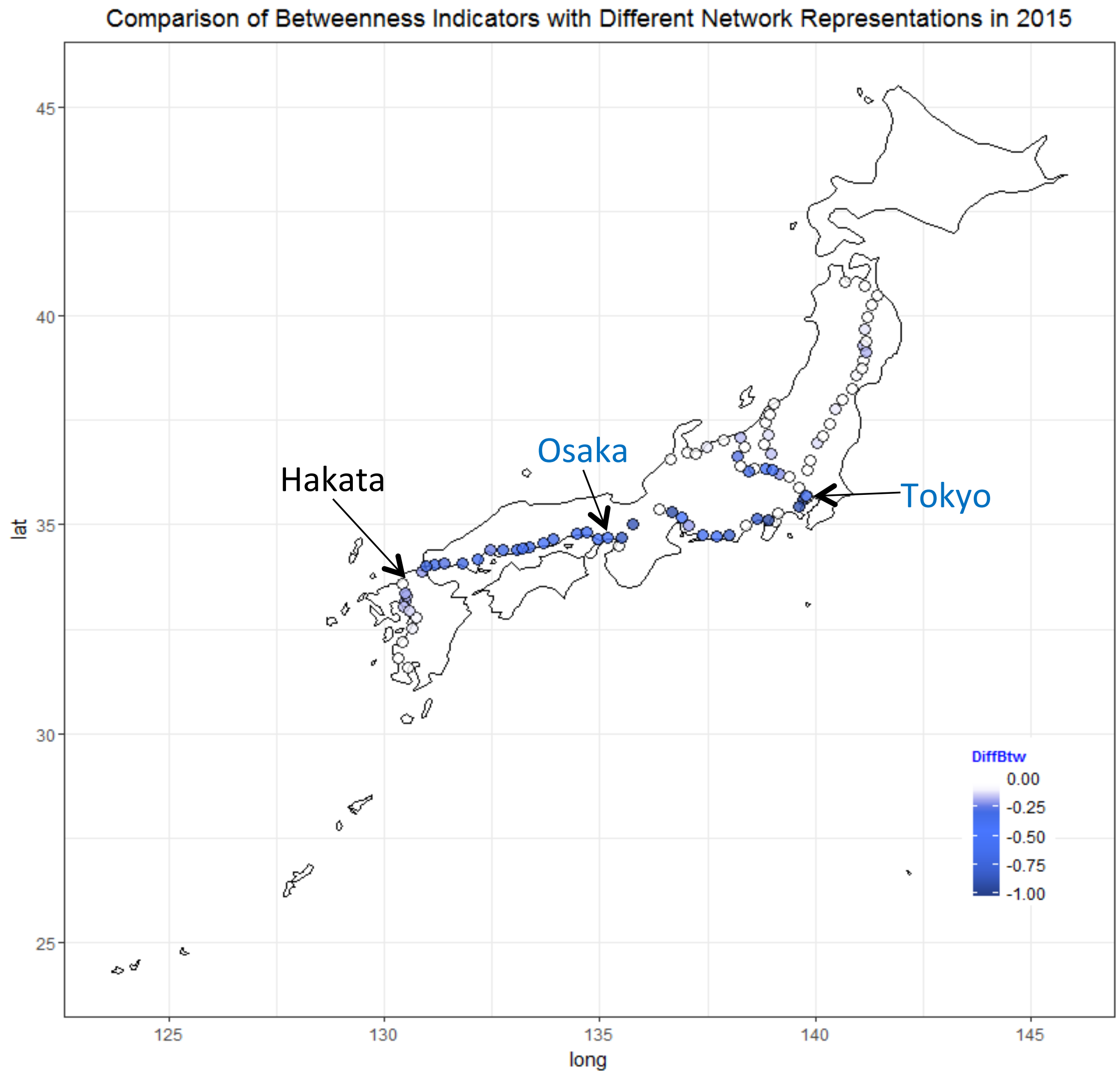
Difference of standardized (0-1) centrality indicators: Service network vs. P-space (Degree)

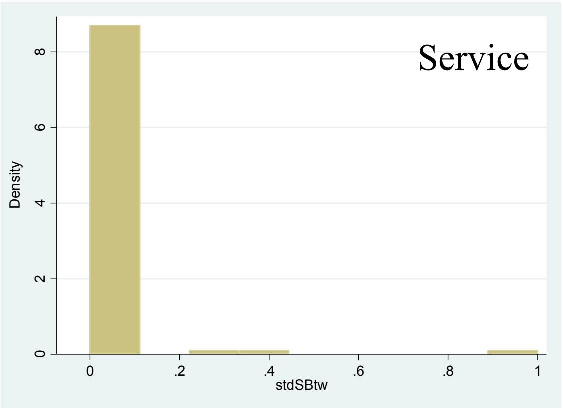


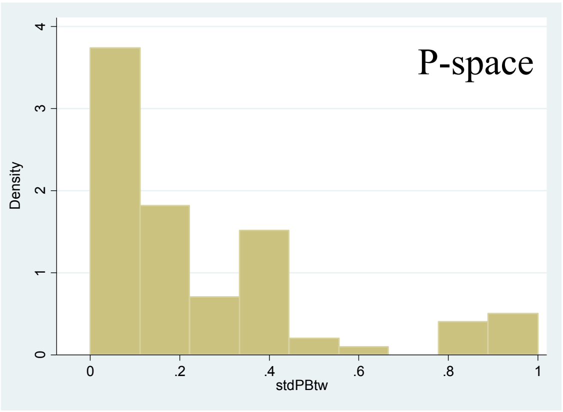




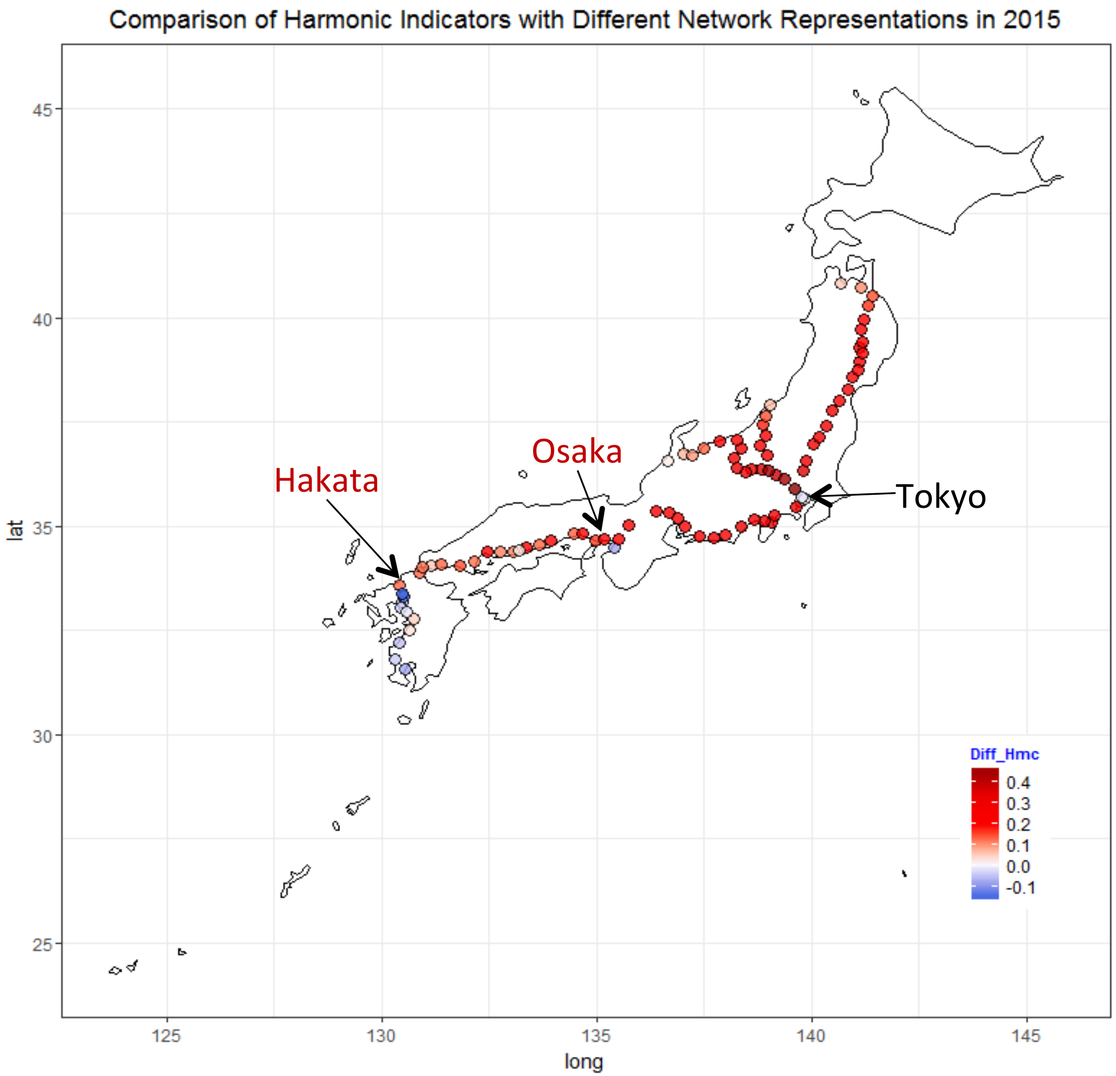
Difference of standardized (0-1) centrality indicators: Service network vs. P-space (Betweenness)

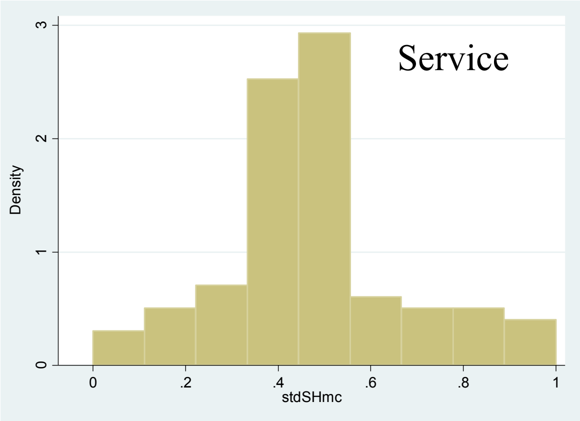


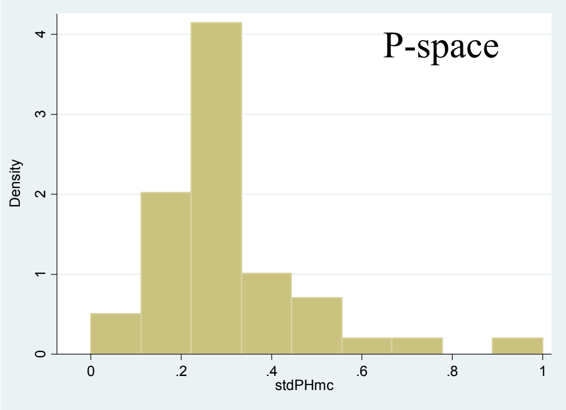




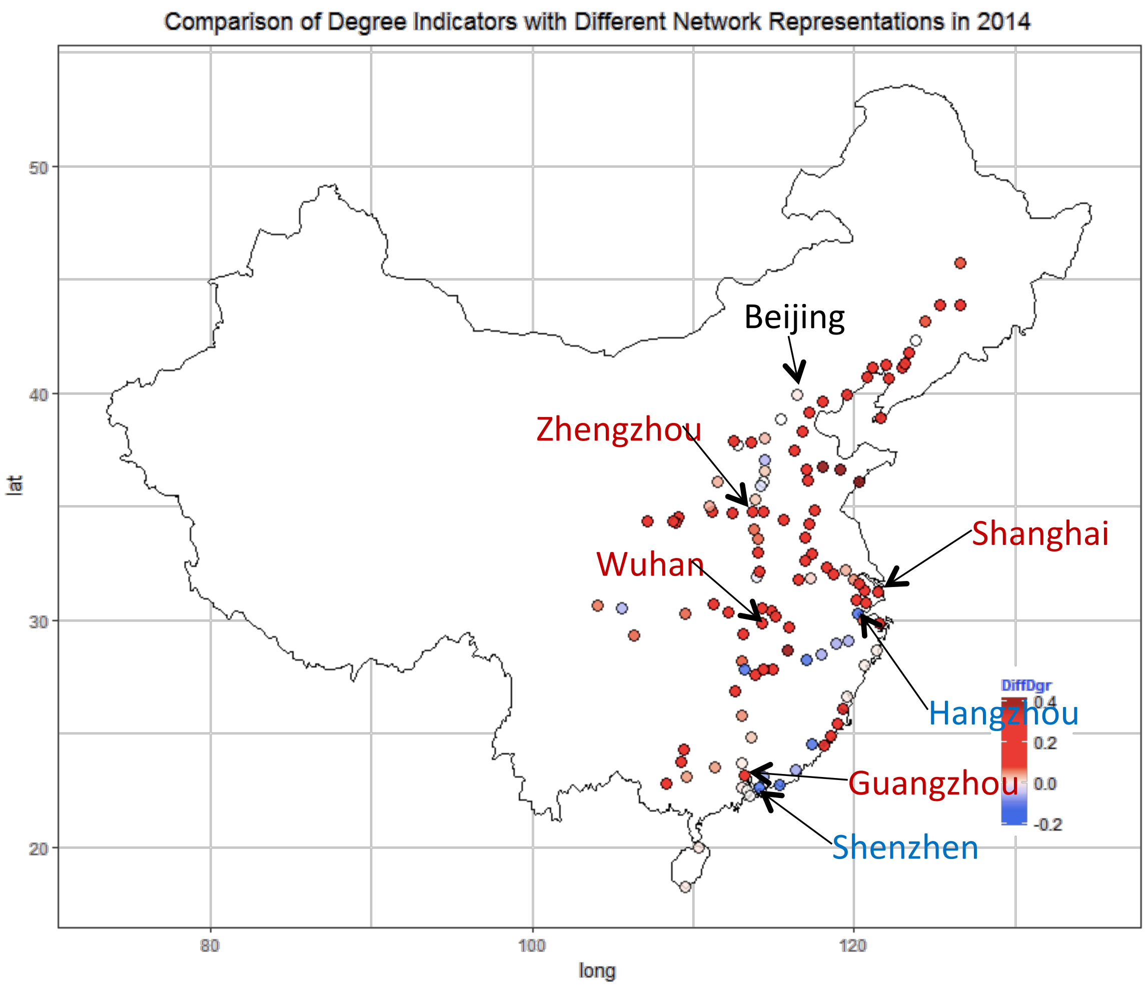
Difference of standardized (0-1) centrality indicators: Service network vs. P-space (Harmonic)

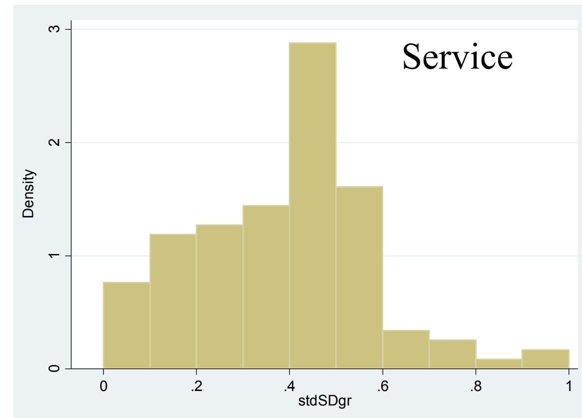


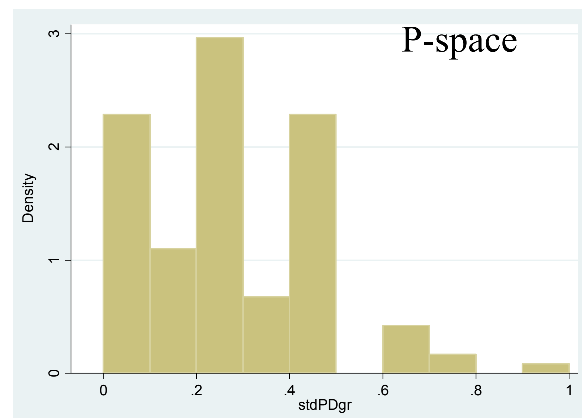




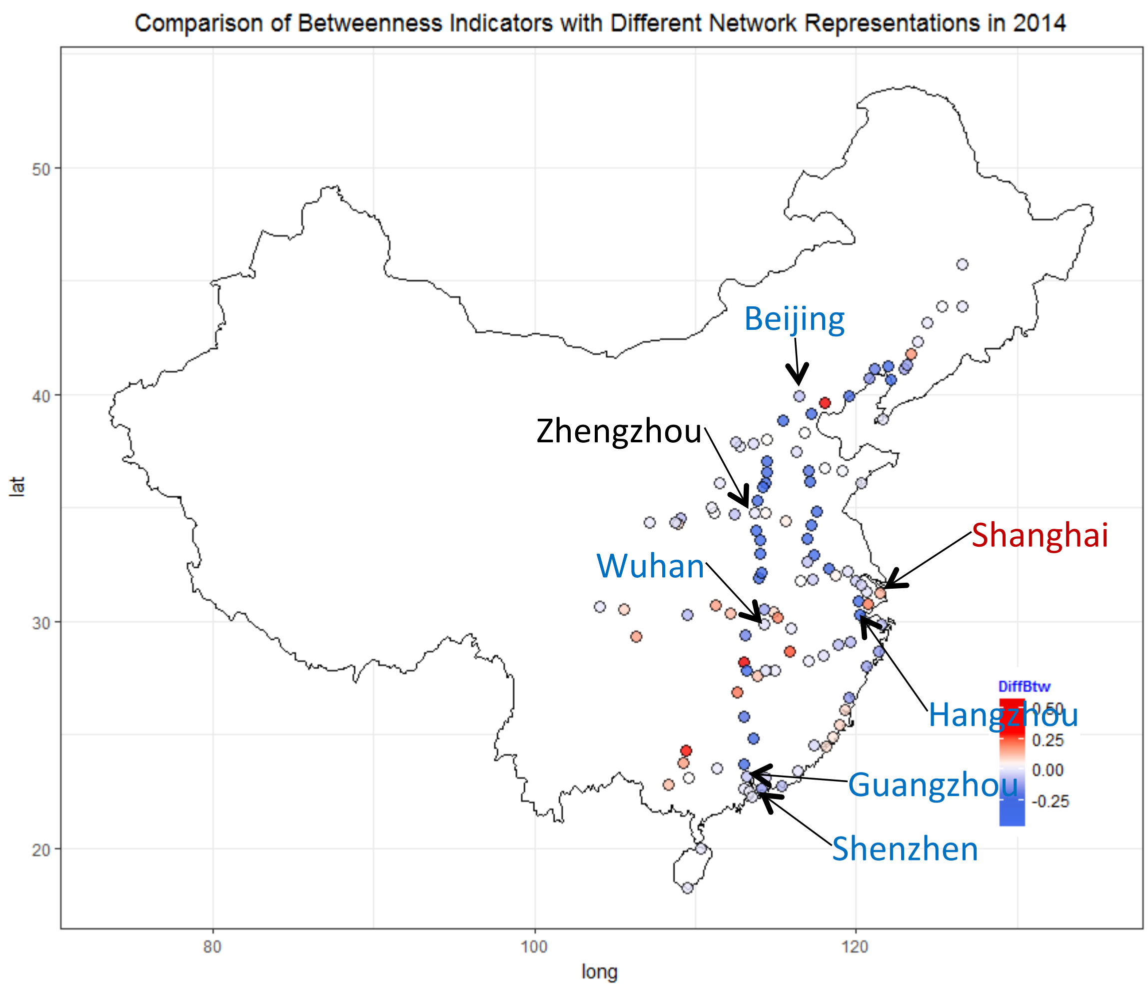
Difference of standardized (0-1) centrality indicators: Service network vs. P-space (Degree)

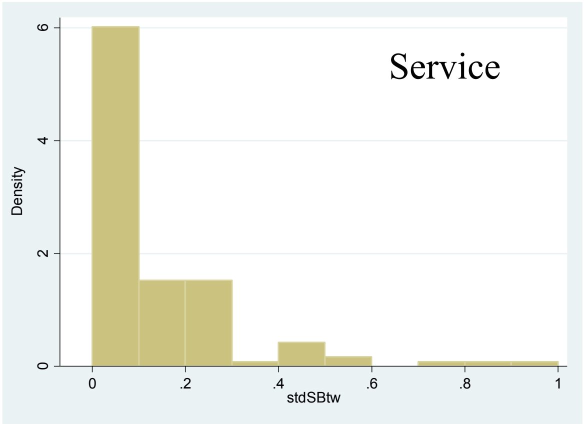


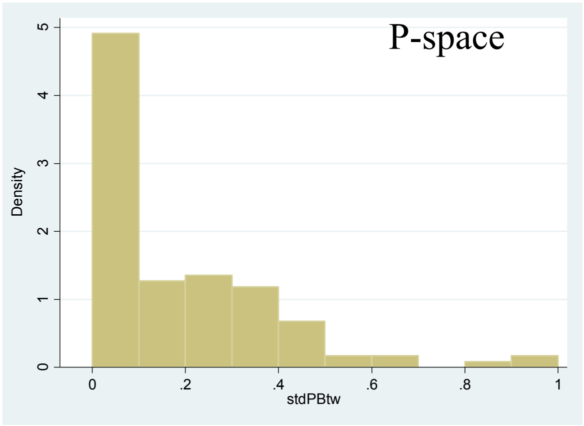




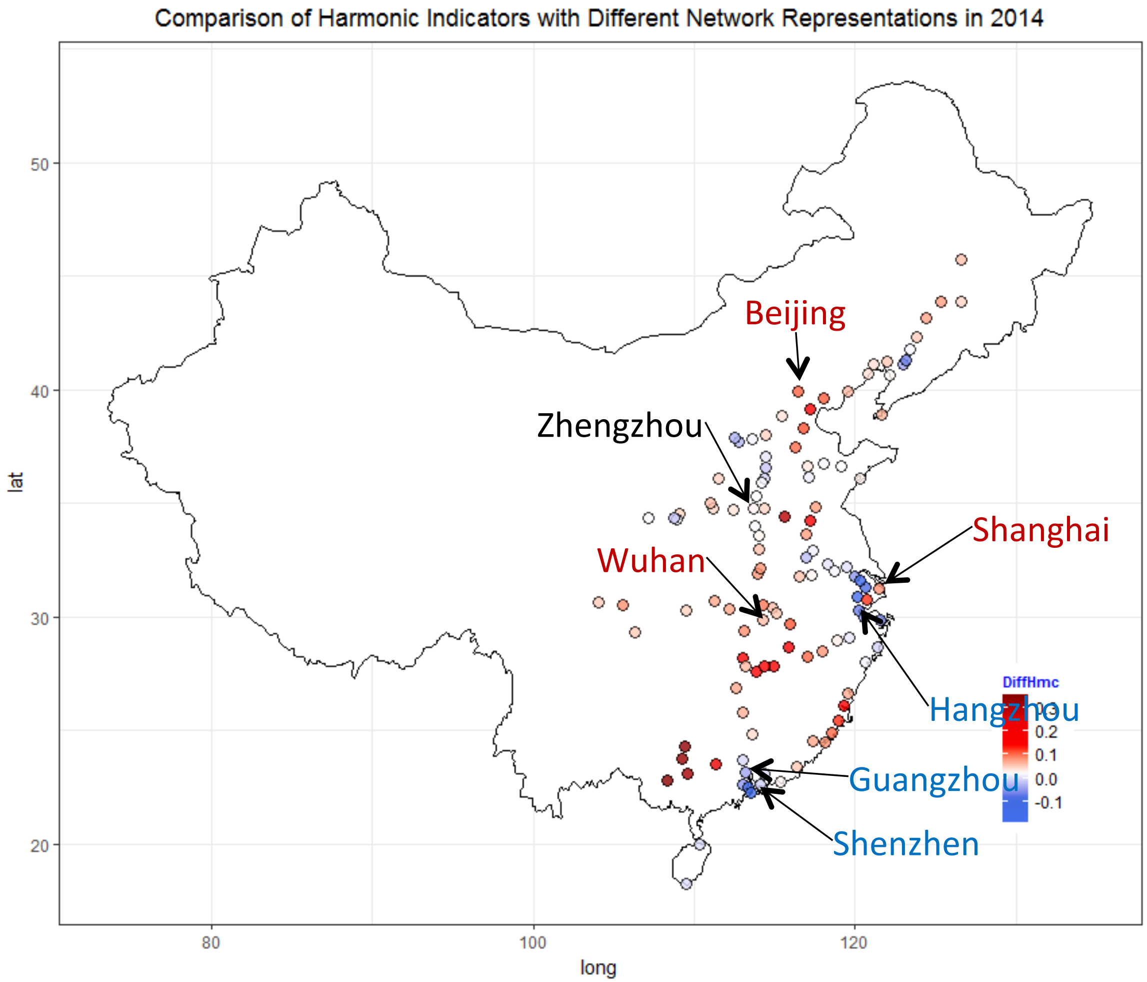
Difference of standardized (0-1) centrality indicators: Service network vs. P-space (Betweenness)

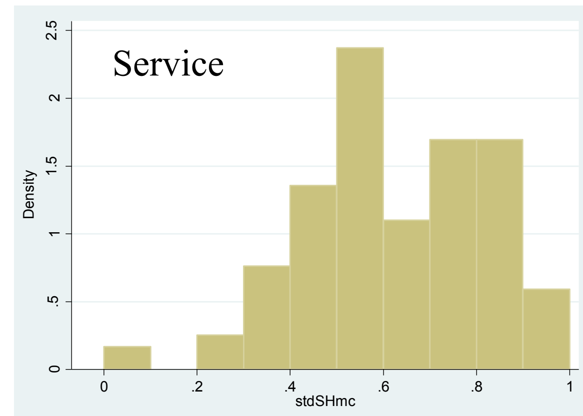


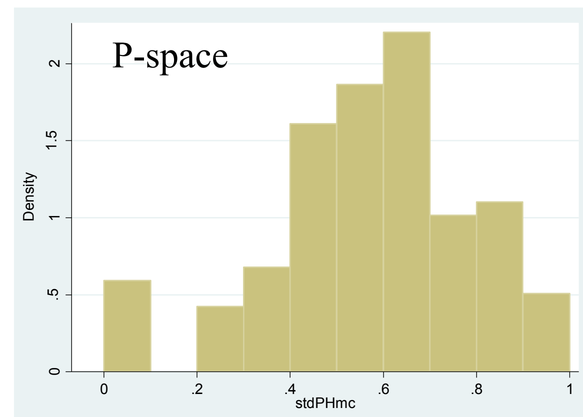




Difference of standardized (0-1) centrality indicators: Service network vs. P-space (Harmonic)







- Importance of cities along the coastal line of South China and those in Guangxi and Sichuan provinces are understated by infrastructure for all the three indicators

- Degree and harmonic centralities of cities in Bohai Rim are understated, while those of many cities in PRD and YRD are overstated by the infrastructure.

- For example, importance of Hangzhou and Shenzhen are overstated by infrastructure for all the three indicators

- Megacities, such as Beijing and Shanghai, are better served by HSR than what reflected by the infrastructure network, but this is not the case for Shenzhen and Guangzhou

Econometric specifications (impact on passenger traffic)

$$\ln Passenger_{it} = \beta_0 + \beta_1 \ln Centrality_{it} + Z_{it}\gamma + u_{it}$$

$$\ln Passenger_{it} = \beta_0 + \beta_2 (\ln Centrality_{it} \times Sef_{it}) + \beta_3 (\ln Centrality_{it} \times Cef_{it}) + Z_{it}\gamma + u_{it}$$

Sef_{it} = city center-airport distance / HSR station-city center distance (0-1 standardized); accessibility of HSR station relative to airport (relative competitiveness of HSR, substitution effect)

Cef_{it} = inverse of airport-HSR station distance (0-1) standardized; convenience of air-HSR transfer (complementary effect)

Z_{it} = control variables for airport i at year t

Control variables

Variables	Labels	Definition
Population	Ln_POP	Log of population in the airport's catchment area
GDP per Capita	Ln_GDP-POP	Log of per capital real GDP in the airport's catchment area (base=2005)
Privatization	Privatization	Percentage of shares hold by private sectors
Low cost carriers	LCC	Number of low cost carriers based in the airport
Corporatization	D_Corp	= 1 if the airport is corporatized
Localization	D_Local	= 1 if the airport is owned by local government
Runway structure	D_Rwystr	= 1 if two runways are too close to each other (< 460m) or have intersections (Guangzhou, Haneda, Shanghai et al.)
Demand Shock	D_Shock	= 1 if financial crisis or major natural disaster happened (e.g. Japan earthquake 2011; China 2008)
Investment	D_Investment	= 1 if major expansion of airport terminal or runway is completed. An increase of total runway length or terminal size by more than 20% is considered as major expansion

Sample and data sources

- Airports handling over 2 million passengers in 2015 in China (46) and Japan (14)

- Period: annual data from 2007 to 2015

- Data sources:
    - HSR Infrastructure: International Railway Union (UIC), China Middle-to-Long-Term Railway Network Plan, Japan Ministry of Land Infrastructure Transport and Tourism
    - HSR Service: China Rail Timetable (2007-2015), July editions; Japan Rail Timetable (2007-2015), March editions
    - Population, real GDP and wage rate: CEIC database for China, Cabinet Office of Japan
    - Airport infrastructure: airport websites, annual reports, telephone interviews, etc.
    - Airport traffic: CAAC, Ministry of Land, Infrastructure and Tourism of Japan

Results: Japan, DV = Ln(Passenger)

	Service network						**P-space infrastructure network**					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Ln(POP)	2.478 (0.215)***	2.256 (0.198)***	2.393 (0.208)***	1.913 (0.193)***	1.907 (0.174)***	1.905 (0.195)***	2.456 (0.220)***	2.856 (0.202)***	2.362 (0.203)***	1.897 (0.193)***	2.215 (0.186)***	1.941 (0.189)***
Ln(GDP-POP)	2.029 (0.593)***	2.973 (0.686)***	1.781 (0.594)***	2.730 (0.616)***	3.133 (0.592)***	2.564 (0.625)***	2.007 (0.600)***	2.432 (0.538)***	2.986 (0.663)***	2.772 (0.614)***	2.409 (0.589)***	3.049 (0.610)***
LCC	0.179 (0.078)**	0.227 (0.081)***	0.171 (0.077)**	0.142 (0.075)*	0.143 (0.075)*	0.139 (0.076)*	0.182 (0.079)**	0.192 (0.070)***	0.202 (0.079)**	0.143 (0.075)*	0.169 (0.074)**	0.157 (0.075)**
Dummy_ Shock	-0.091 (0.133)	-0.059 (0.137)	-0.101 (0.134)	-0.123 (0.127)	-0.125 (0.125)	-0.127 (0.128)	-0.098 (0.135)	-0.040 (0.120)	-0.074 (0.134)	-0.126 (0.127)	-0.091 (0.124)	-0.115 (0.126)
Ln(Dgr)	**-0.387 (0.092)*** **						**-0.391 (0.102)*** **					
Ln(Btw)		**-0.249 (0.069)*** **						**-0.331 (0.046)*** **				
Ln(Hmc)			**-0.133 (0.033)*** **						**-1.514 (0.370)*** **			
Ln(Dgr) * Sef				**-0.652 (0.117)*** **						**-0.719 (0.130)*** **		
Ln(Dgr) * Cef				**0.111 (0.130)**						**0.148 (0.148)**		
Ln(Btw) * Sef					**-0.517 (0.084)*** **						**-0.426 (0.066)*** **	
Ln(Btw) * Cef					**0.102 (0.087)**						**-0.125 (0.079)**	
Ln(Hmc) * Sef						**-0.233 (0.044)*** **						**-2.771 (0.471)*** **
Ln(Hmc) * Cef						**0.043 (0.053)**						**0.165 (0.567)**
Constant	-13.593 (3.376)***	-18.474 (4.194)***	-11.438 (3.268)***	-14.702 (3.266)***	-17.337 (3.248)***	-13.570 (3.297)***	-13.323 (3.423)***	-18.634 (3.170)***	-19.153 (4.068)***	-14.884 (3.259)***	-14.517 (3.179)***	-16.960 (3.305)***
N	128	128	128	128	128	128	128	128	128	128	128	128
Adjusted R-squared	0.7846	0.777	0.782	0.806	0.814	0.801	0.7797	0.826	0.7827	0.806	0.815	0.809

*** significant at the 1% level; ** significant at the 5% level; * significant at 10% level; brackets show standard errors

Results: Japan, DV = Ln(Passenger)

- In terms of net effect, harmonic centrality has the strongest association with passenger numbers in P-space, while degree has the strongest association in service network

- Substitution effect dominates complementary effect

- Results of service network and P-space are consistent for all the centrality indicators

- Passenger traffic is elastic regarding the P-space infrastructure harmonic centrality, but not the other indicators

Results: China, DV = Ln(Passenger)

	P-space infrastructure network					
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(POP)	1.876 (0.291)***	1.795 (0.281)***	1.704 (0.284)***	1.759 (0.286)***	1.760 (0.277)***	1.668 (0.280)***
Ln(GDP-POP)	2.161 (0.076)***	2.139 (0.074)***	2.091 (0.080)***	2.135 (0.074)***	2.118 (0.074)***	2.081 (0.076)***
LCC	0.173 (0.036)***	0.166 (0.037)***	0.158 (0.036)***	0.163 (0.037)***	0.153 (0.037)***	0.150 (0.036)***
Dummy_ Shock	-0.104 (0.023)***	-0.103 (0.023)***	-0.103 (0.023)***	-0.103 (0.023)***	-0.104 (0.023)***	-0.103 (0.023)***
Ln(Dgr)	**-0.025 (0.031)**					
Ln(Btw)		**0.003 (0.012)**				
Ln(Hmc)			**0.248 (0.164)**			
Ln(Dgr) * Sef				**0.050 (0.082)**		
Ln(Dgr) * Cef				**0.028 (0.053)**		
Ln(Btw) * Sef					**0.009 (0.043)**	
Ln(Btw) * Cef					**0.046 (0.025)***	
Ln(Hmc) * Sef						**0.793 (0.803)**
Ln(Hmc) * Cef						**0.640 (0.322)****
Constant	1.108 (1.089)	1.499 (1.027)	2.038 (1.074)*	1.658 (1.059)	1.715 (1.010)*	2.233 (1.043)**
Airport dummy	Yes	Yes	Yes	Yes	Yes	Yes
N	414	414	414	414	414	414
Adjusted R-squared	0.982	0.982	0.982	0.982	0.982	0.982

*** significant at the 1% level; ** significant at the 5% level; * significant at 10% level; brackets show standard errors

Results: China, DV = Ln(Passenger)

- Coefficients of centrality indicators are in general statistically insignificant in L-space and P-space infrastructure networks

- There seems some complementary effect with respect to harmonic centrality in infrastructure networks

Impact on airport efficiency

Tobit regression

$$\ln E_{it}^{*} = \beta_0 + \beta_1 \ln Centrality_{it} + Z_{it}\gamma + u_{it}$$

$$\ln E_{it}^{*} = \beta_0 + \beta_2 (\ln Centrality_{it} \times Sef_{it}) + \beta_3 (\ln Centrality_{it} \times Cef_{it}) + Z_{it}\gamma + u_{it}$$

$$E_{it} = \begin{cases} 1 & \text{if } E_{it}^{*} \geq 1 \\ E_{it}^{*} & \text{if } E_{it}^{*} < 1 \end{cases}$$

E_{it} = Efficiency scores obtained from Data Envelopment Analysis (DEA). DEA scores belong to the range (0, 1].

DEA

- Non-parametric technique that uses mathematical programming to identify the efficient frontier for a set of Decision Making Units (DMUs) with multiple outputs and inputs
- Constant returns to scale model (CRS): Charnes, Cooper and Rhodes (1978, 1981)
- Variable returns to scale model (VRS): Banker, Charnes and Cooper (1984)
    - Input-oriented model: minimize inputs while producing at least the given output levels
    - Output-oriented model: maximize outputs while using no more than the observed amount of inputs
- This study:
    - CRS and output-oriented VRS
    - Outputs: passenger throughput, cargo throughput, aircraft movement
    - Inputs: total runway length, total terminal area, number of employees

Results: Japan, DV = VRS DEA scores

	Service Network						P-space Infrastructure Network					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Ln(POP)	0.196 (0.062)***	0.237 (0.061)***	0.204 (0.061)***	0.105 (0.059)*	0.101 (0.057)*	0.105 (0.059)*	0.198 (0.063)***	0.294 (0.062)***	0.184 (0.059)***	0.102 (0.058)*	0.215 (0.054)***	0.099 (0.059)*
Ln(GDP-POP)	0.094 (0.172)	0.077 (0.189)	0.128 (0.173)	0.453 (0.170)***	0.458 (0.161)***	0.453 (0.170)***	0.108 (0.173)	0.213 (0.181)	-0.115 (0.185)	0.450 (0.163)***	0.495 (0.164)***	0.421 (0.167)**
Privatization	-0.855 (0.154)***	-0.908 (0.153)***	-0.875 (0.152)***	-0.888 (0.136)***	-0.765 (0.134)***	-0.888 (0.136)***	-0.849 (0.155)***	-0.986 (0.157)***	-0.807 (0.152)***	-0.815 (0.135)***	-0.647 (0.138)***	-0.801 (0.137)***
LCC	0.062 (0.024)***	0.062 (0.024)**	0.063 (0.024)***	0.046 (0.021)**	0.048 (0.020)**	0.046 (0.021)**	0.062 (0.024)***	0.067 (0.024)***	0.057 (0.023)**	0.051 (0.021)**	0.047 (0.021)**	0.047 (0.021)**
Dummy_Corp	-0.088 (0.044)**	-0.075 (0.044)*	-0.087 (0.044)*	-0.013 (0.041)	-0.023 (0.039)	-0.013 (0.041)	-0.094 (0.045)***	-0.053 (0.044)	-0.083 (0.043)*	-0.021 (0.039)	-0.084 (0.039)**	-0.015 (0.041)
Dummy_ Local	0.212 (0.056)***	0.236 (0.055)***	0.216 (0.056)***	0.242 (0.049)***	0.212 (0.047)***	0.242 (0.049)***	0.218 (0.056)***	0.281 (0.059)***	0.190 (0.055)***	0.229 (0.048)***	0.197 (0.049)***	0.210 (0.049)***
Dummy_Rwy	0.148 (0.046)***	0.170 (0.047)***	0.149 (0.046)***	0.180 (0.039)***	0.185 (0.038)***	0.180 (0.039)***	0.143 (0.047)***	0.164 (0.044)***	0.133 (0.045)***	0.189 (0.039)***	0.113 (0.040)***	0.171 (0.039)***
Dummy_Shock	-0.061 (0.034)*	-0.059 (0.035)*	-0.060 (0.034)*	-0.066 (0.031)**	-0.063 (0.030)**	-0.066 (0.031)**	-0.060 (0.034)*	-0.049 (0.034)	-0.067 (0.033)**	-0.062 (0.030)**	-0.064 (0.030)**	-0.067 (0.030)**
Dummy_Invest	-0.005 (0.029)	-0.004 (0.029)	-0.004 (0.029)	-0.020 (0.026)	-0.025 (0.026)	-0.020 (0.026)	-0.005 (0.029)	-0.001 (0.029)	-0.008 (0.028)	-0.025 (0.026)	-0.017 (0.026)	-0.022 (0.026)
Ln(Dgr)	**0.048 (0.025)***						**0.049 (0.028)***					
Ln(Btw)		**0.008 (0.019)**						**-0.029 (0.015)***				
Ln(Hmc)			**0.016 (0.009)***						**0.294 (0.101)*****			
Ln(Dgr) * Sef				**-0.094 (0.029)*****						**-0.104 (0.032)*****		
Ln(Dgr) * Cef				**0.168 (0.033)*****						**0.177 (0.036)*****		
Ln(Btw) * Sef					**-0.059 (0.024)*****						**-0.100 (0.018)*****	
Ln(Btw) * Cef					**0.101 (0.021)*****						**0.057 (0.021)*****	
Ln(Hmc) * Sef						**-0.173 (0.048)*****						**-0.281 (0.118)*****
Ln(Hmc) * Cef						**0.320 (0.063)*****						**0.764 (0.155)*****
Constant	-1.260 (1.022)	-1.386 (1.173)	-1.539 (1.005)	-2.998 (0.919)***	-3.024 (0.993)***	-3.030 (0.912)***	-1.362 (1.017)	-0.411 (1.147)	0.176 (1.160)	-2.979 (0.921)***	-3.961 (0.974)***	-2.782 (0.972)***
N	128	128	128	128	128	128	128	128	128	128	128	128
LR chi2	121.53	118.14	121.30	153.58	148.63	155.11	120.95	122.73	126.17	152.51	153.96	148.65
Log likelihood	69.207	67.514	69.091	85.231	82.759	85.995	68.919	69.809	71.526	84.699	85.421	82.769

*** significant at the 1% level; ** significant at the 5% level; * significant at 10% level; brackets show standard errors

Results: Japan, DV = VRS DEA scores

- Harmonic centrality has the strongest association with airport technical efficiency than the other indicators in both substitution and complementary effects

- The net impact on airport efficiency tends to be positive for degree and harmonic centralities, as complementary effect dominates substitution effect and both are statistically significant

- Betweenness has relatively little impact

Results: China, DV = DEA scores, P-space

	CRS						VRS					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Ln(POP)	0.576 (0.185)***	0.592 (0.178)***	0.588 (0.181)***	0.497 (0.180)***	0.587 (0.175)***	0.562 (0.178)***	0.396 (0.204)*	0.460 (0.197)**	0.445 (0.201)**	0.358 (0.200)*	0.467 (0.195)**	0.436 (0.198)**
Ln(GDP-POP)	0.177 (0.049)***	0.181 (0.048)***	0.179 (0.052)***	0.158 (0.048)***	0.160 (0.048)***	0.161 (0.050)***	0.165 (0.055)***	0.177 (0.054)***	0.167 (0.059)***	0.157 (0.053)***	0.163 (0.054)***	0.161 (0.056)***
Privatization	0.059 (0.091)	0.059 (0.092)	0.059 (0.091)	0.047 (0.091)	0.071 (0.091)	0.049 (0.091)	0.050 (0.105)	0.054 (0.105)	0.053 (0.105)	0.034 (0.104)	0.063 (0.105)	0.042 (0.105)
LCC	0.018 (0.024)	0.019 (0.025)	0.018 (0.024)	0.011 (0.024)	0.010 (0.025)	0.017 (0.024)	0.090 (0.028)***	0.092 (0.028)***	0.093 (0.028)***	0.085 (0.027)***	0.085 (0.028)***	0.091 (0.028)***
Dummy_Corp	0.080 (0.049)	0.082 (0.050)	0.081 (0.050)	0.052 (0.050)	0.043 (0.055)	0.045 (0.054)	0.077 (0.054)	0.077 (0.058)	0.077 (0.055)	0.049 (0.055)	0.042 (0.061)	0.047 (0.061)
Dummy_Rwy	-0.116 (0.047)**	-0.116 (0.047)**	-0.116 (0.047)**	-0.118 (0.047)**	-0.114 (0.047)**	-0.116 (0.047)**	-0.071 (0.053)	-0.068 (0.053)	-0.067 (0.053)	-0.071 (0.053)	-0.067 (0.053)	-0.066 (0.053)
Dummy_Shock	-0.031 (0.015)**	-0.031 (0.015)**	-0.031 (0.015)**	-0.030 (0.015)**	-0.031 (0.015)**	-0.030 (0.015)**	-0.028 (0.016)*	-0.029 (0.016)*	-0.028 (0.016)*	-0.027 (0.016)*	-0.029 (0.016)*	-0.028 (0.016)*
Dummy_Invest	-0.057 (0.013)***	-0.057 (0.013)***	-0.057 (0.013)***	-0.055 (0.013)***	-0.057 (0.013)***	-0.055 (0.013)***	-0.053 (0.015)***	-0.052 (0.015)***	-0.052 (0.015)***	-0.051 (0.015)***	-0.052 (0.015)***	-0.051 (0.015)***
Ln(Dgr_PpInf)	**0.006 (0.020)**						**0.030 (0.022)**					
Ln(Btw_PpInf)		**0.001 (0.008)**						**0.006 (0.009)**				
Ln(Hmc_PpInf)			**0.013 (0.107)**						**0.090 (0.120)**			
Ln(Dgr_PpInf) * Sef				**-0.078 (0.051)**						**-0.054 (0.057)**		
Ln(Dgr_PpInf) * Cef				**0.086 (0.035)*** **						**0.102 (0.038)*****		
Ln(Btw_PpInf) * Sef					**-0.048 (0.027)***						**-0.039 (0.030)**	
Ln(Btw_PpInf) * Cef					**0.035 (0.018)***						**0.038 (0.020)***	
Ln(Hmc_PpInf) * Sef						**-1.101 (0.508)****						**-0.551 (0.568)**
Ln(Hmc_PpInf) * Cef						**0.478 (0.227)****						**0.431 (0.253)****
Constant	-2.381 (0.694)***	-2.460 (0.654)***	-2.439 (0.686)***	-1.955 (0.671)***	-2.325 (0.641)***	-2.218 (0.669)***	-1.506 (0.767)*	-1.804 (0.724)**	-1.699 (0.762)**	-1.277 (0.743)*	-1.741 (0.712)**	-1.597 (0.747)**
Airport Dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	414	414	414	414	414	414	414	414	414	414	414	414
LR chi2	738.21	738.11	738.12	745.11	743.64	745.24	739.36	738.02	738.11	744.64	741.85	740.72
Log likelihood	412.193	412.142	412.148	415.645	414.908	415.711	347.223	346.551	346.598	349.865	348.468	347.905

*** significant at the 1% level; ** significant at the 5% level; * significant at 10% level; brackets show standard errors

Results: China, DV = DEA scores, P-space

- In infrastructure network, complementary effect tends to be statistically significant but not substitution effect

- The net effect seems very small

- Harmonic centrality seems slightly more strongly associated with airport efficiency than the other indicators

Summary results from models with main effects, Japan, DV = VRS DEA scores

$$\ln E_{it}^{*} = \beta_0 + \beta_1 \ln Centrality_{it} + \beta_2(\ln Centrality_{it} \times Sef_{it}) + \beta_3(\ln Centrality_{it} \times Cef_{it}) + Z_{it}\gamma + u_{it}$$

	Service Network			P-space Infrastructure Network		
	Degree	Betweenness	Harmonic	Degree	Betweenness	Harmonic
β1	0.129 (0.039)***	0.056 (0.037)	0.049 (0.014)***	0.135 (0.046)***	-0.037 (0.024)	0.584 (0.141)***
β2	-0.209 (0.044)***	-0.134 (0.038)***	-0.083 (0.016)***	-0.223 (0.051)***	-0.070 (0.027)***	-0.773 (0.162)***
β3	0.057 (0.046)	0.026 (0.041)	0.026 (0.017)	0.062 (0.052)	0.093 (0.032)***	0.242 (0.191)

Sample size = 128

Summary results from models with main effects, China, DV = CRS or VRS DEA scores, P-space

$$\ln E_{it}^{*} = \beta_0 + \beta_1 \ln Centrality_{it} + \beta_2(\ln Centrality_{it} \times Sef_{it}) + \beta_3(\ln Centrality_{it} \times Cef_{it}) + Z_{it}\gamma + u_{it}$$

	CRS			VRS		
	Degree	Betweenness	Harmonic	Degree	Betweenness	Harmonic
β1	-0.076 (0.034)**	-0.036 (0.016)**	-0.335 (0.191)*	-0.037 (0.038)	-0.022 (0.018)	-0.152 (0.215)
β2	-0.056 (0.052)	-0.037 (0.027)	-0.938 (0.514)*	-0.044 (0.058)	-0.032 (0.031)	-0.479 (0.576)
β3	0.187 (0.057)***	0.102 (0.034)***	1.026 (0.386)***	0.151 (0.063)**	0.078 (0.038)**	0.679 (0.433)

Sample size = 414

Concluding remarks

- Among different measures of a city's importance in the HSR network, harmonic centrality seems to be the most relevant to air airport performance.
- Airports located at the "center" of the HSR network are the most affected, followed by those with good connectivity to other cities by HSR.
- In Japan, substitution effect is stronger than complementary effect for passenger traffic volume but the opposite holds for airport efficiency.
- In Japan, centrality indicators are relatively consistent with different network representations, leading to consistent regression results.

- In China, HSR centrality indictors appear less associated with airport performance when infrastructure network is in concern.

- Future study: Network representation substantially affects centrality of Chinese cities in our sample. We may see a stronger impact on airports by conducting regression analysis based on China's service network.