Analyze the Spatial Inequality Trends in the U.S. Megaregions

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<tr><td colspan="4">16. Abstract
There have been growing concerns around the world over the rising spatial inequality (SI) and persistent efforts to reduce SI. This report presents an effort to benchmark the conditions of spatial inequality in the territorial scale of megaregions. In addition, the study explored the role of high-speed rail (HSR) as an infrastructure investment approach to reshape, or desirably to reduce SI. In this study SI was assessed with Gini and Coefficient-of-Variance (CV) and rank-size coefficient of polycentricity. Three megaregion cases, The Texas Triangle (USA), The Northern Powerhouse (UK), and The Mid-Yangtze River City Cluster, were selected to analyze the effects of HSR in modifying the level and distribution of accessibility to employment and wealth. HSR elevates mobility by reducing travel times. Yet its role in reducing spatial inequality is contingent on the geographic coverage of HSR network, the pre-existing level of mobility of the served region, and the integration with other transportation systems to reach non-HSR locations. The report demonstrates that multi-continental studies contribute to the knowledge base on strategic spatial planning and improve understanding of both the effectiveness and limitations of major transportation investments (HSR in this case) to address SI challenges under different national and regional context.</td></tr>
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Executive Summary

There have been growing concerns around the world over the rising spatial inequality (SI) and persistent efforts to reduce SI. This report presents an effort to benchmark the conditions of spatial inequality in the territorial scale of megaregions. In addition, the study explored the role of the potential high-speed rail (HSR) as an infrastructure investment approach to reshape, or desirably to reduce SI of accessibility.

The study applies Gini-coefficient, Coefficient-of-Variance (CV) and rank-size coefficient of polycentricity to demonstrate both the SI and polycentricity of 37 megaregions in the US, northwest European and China. Next, the study selects three megaregions in each continent and explore the changes of SI on accessibility before and after the operation (or potential operation) of HSR.

The study found that although megaregions in China showed the highest SI among the three continents, 14 of 19 them experienced a decline in income inequality from 2006 to 2016. SI in the northwest Europe and US varies where those contains global cities tend to have larger SI than those polycentric megaregions. The SI increased in megaregions with large high-tech and professional industries, such as Northern and Southern California, Cascadia, Northeast, and Florida, while decreases in second industry dominated megaregions such as Gulf Coast. The SI changes in accessibility before and after HSR also vary by contexts. For megaregions with traditional rail lines such as UK, the increase in both accessibility and SI is lower than those with insufficient mobility.

Chapter 1. Introduction

The core interest of this report is to explore spatial inequality (SI) and the role of major transportation investments, specifically high-speed rail (HSR), in shaping SI of large-sized regions or megaregions. SI denotes the unequal distribution of resources and opportunities (jobs, education, and health services, et al.) over an area of natural and built environment. Serious spatial inequality may lead to increased regional disparity, environmental injustice, and social instability. Reducing SI is the ongoing effort of international organizations, national governments, and regional as well as local agencies [1,2]. Among many strategies taken to reduce SI, investing in major transportation infrastructure has been a common one [3]. It is expected that improved transportation infrastructure help elevate mobility and enhance access to opportunities and consequently promote balanced development between constituents of regions and population groups for long term sustainability. A notable example is the European Union's European Spatial Development Perspective (ESDP) [4]. ESDP aimed to improve territorial coherence and develop multimodal Trans-European Transportation Network (TEN-T).

Parallel to the growing interest in reducing SI, there are worldwide attentions to the growing importance of megaregions [5–8]. Megaregions refer to large geographies crossing multiple jurisdictions or countries. In the US context, a megaregion consists of two or more metropolitan areas and their integrated hinterland. In Europe and Asia, similar mega-agglomerations also exist while expressed in different terms, for instance, Mega-City Regions in Europe and City-Cluster Regions in China. It has been reported widely that global competitions are taking place increasingly at the megaregion level.

While SI has long been a subject of academic inquiry and public policy debates, it has gained further attention lately concerning the local and regional consequences of eco-nomic globalization [9]. A new wave of research on SI has accumulated new empirical evidence and shed new lights on SI conditions and dimensions, factors contributing to SI, and policy alternatives to address SI concerns [10]. Majority of these studies however have examined SI following the conventional geographies, e.g., cities or counties, metropolitan areas, states or countries. Few looked at SI from a megaregional perspective de-spite strong policy and investment interests in megaregions.

This study examines the SI in megaregions from three different contexts, the US, Northeast Europe, and China. All three regions have multiple studies on nation-wide/cross-national megaregion studies in past two decades.

At the same time, megaregion studies tend to stay within the continental boundary although conceptually scholarly work refers to the work across continents. HSR investment appears to be a frequently advocated strategy to balance megaregional development. For instance, in China, building national HSR grid as part of national spatial development plan to bridge the gap between the West and the East [11]. In the UK, the Northern Powerhouse initiative aimed to reduce the disparity between the North and the South of England through HSR and other infrastructure investments [12]. In the United States, there have been recommendations to invest in HSR to regenerate the bypassed and underdeveloped communities. Nevertheless, there have been no studies to analyze the implications of investing HSR for reducing SI in a cross-continental setting of megaregion framework.

The study presented in this report sets a twofold objective. First, the study aims to benchmark the SI condition and trend of megaregions in multiple continents. Second, the study explores the effects (revealed or potential) of major transportation investments in reshaping SI of megaregions. It is expected that the multi-continental SI studies will con-tribute to the knowledge base on strategic spatial planning and improve understanding of both the effectiveness and limitations of investing in HSR to address SI challenges under different national or regional context.

The rest of the report consists of four parts. Part 2 introduces megaregion study background and reviews related studies on SI and megaregions. Part 3 presents study method, describing study approach, data sources, and SI indicators. Part 4 presents SI analysis results and findings. Finally, the report ends with concluding remarks and discussions on future research.

Chapter 2. Background and Related Studies

2.1. Background on Megaregion Interest

Megaregions, or mega-city regions in Europe and city-cluster regions in China, can find their conceptual origin from megalopolis observed by French geographer Jean Gottman (1961) and World City analyzed by Peter Hall (1966) in the 1950's ~1960's. The renewed interest in megaregions beginning after the turn of the 21 century lies in the premise that, in the globalized economy, it is these mega-agglomerations, not individual cities, that play a key role for competition. The US projections show that three fourths of U.S. jobs and population will concentrate in the eleven megaregions by 2050. While a number of scholars have come up with their own delineations of US megaregions [13–16], a view shared by them is the urgent research needs to understand megaregional challenges and devise a megaregional approach to address issues in multiple dimensions institutional/legal, analytical, environmental, and social. The U.S. Department of Transportation (DOT) published its strategic plan in 2016, "Beyond Traffic 2045: Trends and Choices", which highlights the significance of megaregions to the nation's future and calls for actions (Figure 1). From 2016 to 2018, US FHWA organized nine megaregion workshops across the country to facilitate discussions on key issues surrounding megaregions such as economic vitality, environment/air quality, freight, infrastructure/congestion, and safety. Each event focused on issues specific to that megaregion and included efforts to create dialogue regarding common transportation topics of mutual concern across juris-dictional boundaries.

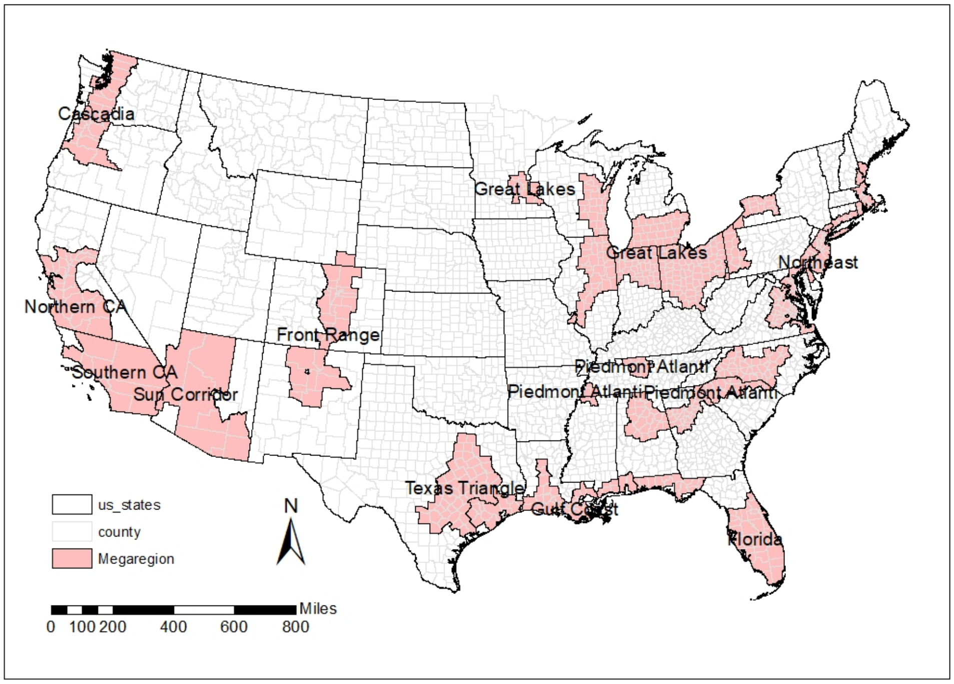


Figure 1. Eleven Megaregions in the United States

Europe has a long history of studying multi-regional spatial strategies for development and policymaking. One recent major effort was Polynet, a multi-year effort led by Peter Hall and Kathy Pain (2006) with networked researchers from the UK, Belgium, France, Ireland, the Netherlands and Switzerland. Polynet identified seven mega-city regions in north-west Europe and examined changes in functional connections and spatial relations indicated by information flows between and within the mega-city regions (Figure 2). The project established a Transnational Policy Network that aimed at promoting the development of cooperative plans to promote polycentricity and enhance interconnections at multiple level of spatial development, policy making, and investment decisions. Polynet's study findings informed the development of the NWE Spatial Vision and the European Spatial Development Perspective (ESDP), an EU scale initiative started in the 1990's.

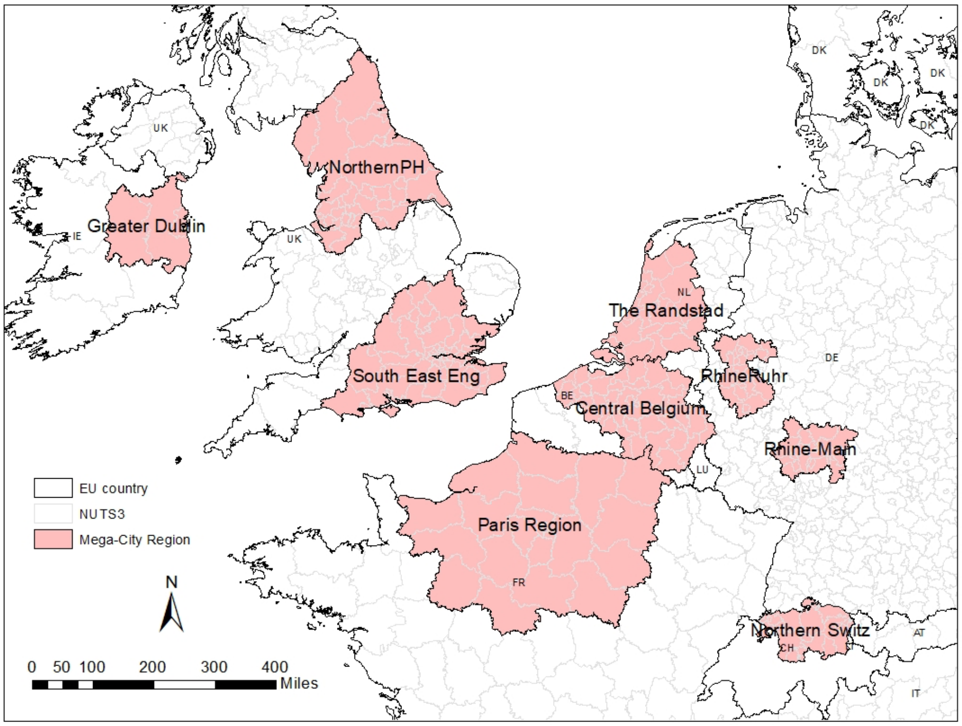


Figure 2. Nine Mega-City Regions in the Northeast Europe

China's city-cluster regional development initiative took a top-down approach. A city-cluster region consists of multiple large or super-large cities along with an array of intermediate sized cities or counties and their hinterlands. The idea of accentuating future development in city-cluster regions began in China's 11th Five Year Socioeconomic Development Plan. As China moves into its 13th Five Year Socioeconomic Development Plan, developing a total of 19 city-clusters has become an essential component of the national urbanization strategy. As of mid-2019, the State Council has approved development plans for eight of the 19 city-cluster regions (Figure 3). The city-cluster plans set multiple economic and social development objectives; one of which aims at reducing disparities between regions and promoting balanced growth between cities and rural areas in regions. The national railway plans in 2008 and 2016 officially stated the investment in HSR as an important infrastructure development strategy to implement the city-cluster regional plan [17].

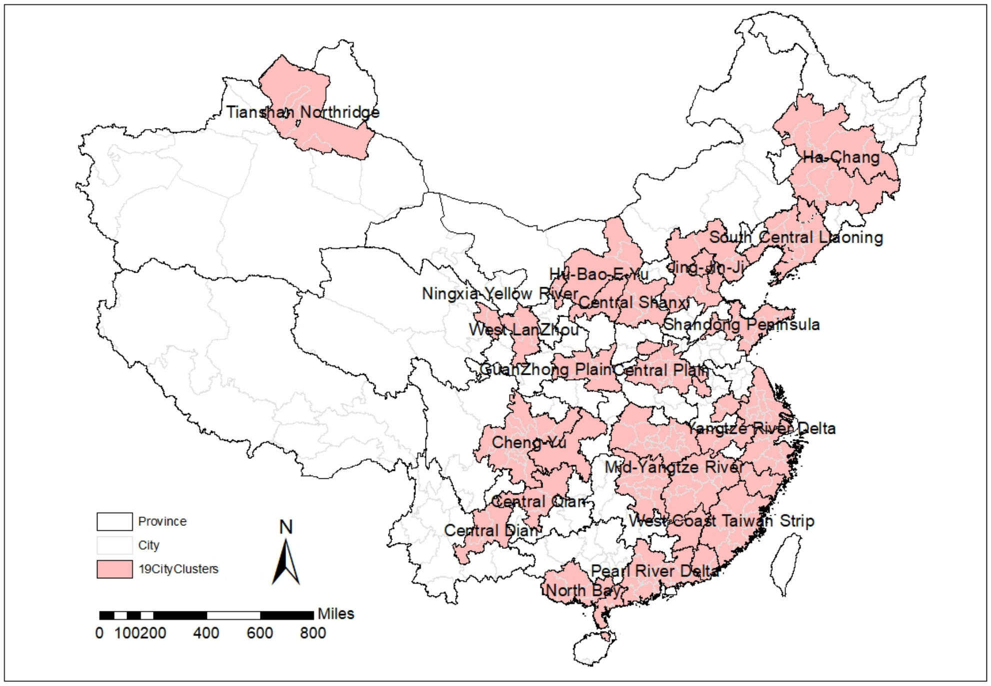


Figure 3. Nineteen City Clusters in China

2.2. General Study of Spatial Inequality

Depending on the standpoint of economic efficiency or social equity, SI may be viewed as a positive or a negative spatial phenomenon [2]. SI may appear positive if resulting from regional specialization with comparative advantages and returns to scale in production. On the other hand, SI may present social challenges if resulting from the spatial concentration of poverty, pollution, and decline. Recent interest in SI has grown out of the observed rising negative SI around the world [18]. International organizations such as the United Nations and the World Bank as well as many national and regional agencies have devoted effects to understand factors contributing to the growing negative SI and to identify intervention strategies, for instance, transportation infrastructure in-vestments, to improve spatial equality.

Studies on regional economic inequality are mainly focused on characterizing the process of convergence (declining SI) or divergence (increasing SI). Empirical studies in the United States since the 1950s have shown an increase of systematic inequality, indicating the new shifts of economic growth on the regional basis [19]. Studies on economics have indicated an inverted U-shaped inequality pattern showing the development within a region tends to diverge at the beginning period of the growth and then converge as the wealth accumulates. [20,21]. Initially tested in personal and regional income distribution within a region, this concept has been generalized in spatial econometrics indicating that the inverted U-shaped pattern fits into regional inequality as well. Scholars developed convergence indices (measured by Coefficient of Variance of per capita income in logarithmic terms) to quantify regional inequality and to investigate the spatial externality of the observed SI convergence/divergence [22]. Studies on megaregional SI were scarce, with a few exceptions [23,24].

In the Chinese context, Wei (1999) examined the development trends in the pre-economic reform period (1949-1978) and the post-reform period (after 1978). He observed a declining regional inequality trend in the pre-reform period when the Central Government adopted distributive policies to balance inter-regional resources. The post-reform period, however, witnessed an increasing regional inequality, especially a divergence between coastal areas and inner regions [25].

An essential feature of SI is multiscalarity – SI varies by the spatial scale of geography where SI is addressed [18]. Existing studies have examined SI at the spatial scales varying by city sizes and by national and international territories [26–28]. This multiscalarity makes the study of SI subject to the challenge of MAUP (Modifiable Area Unit Problem) – which refers to the observation that analysis results of SI vary depending on the scale and composition of geographic unit of analysis. Detailed examination on the nature of MAUP for SI goes beyond the scope of this report. This study selects megaregions as the study scale consistent with the planning and policy interest in megaregions.

2.2.1. Studies on HSR and SI

HSR services shorten space-time distance and thus reshape the spatial access to opportunities over the built and natural environment. The technological and service characteristics of HSR determine that HSR's impacts do not distribute uniformly across the geography but favor the locations near HSR stations and along the HSR lines. This raises questions concerning the distributional effects of HSR on reducing or worsening spatial inequality. Chen and Hall (2012) reported the European experience, suggesting that HSR might generate polarization effects around stations and HSR-rich cities. The polarization effects consequently increase inequality and disparity in multiple dimensions and spatial scales, for instance, between HSR- and non-HSR cities, among different socioeconomic and demographic groups, between cities of different sizes, and between different parts of territorial regions [29].

The European experience demonstrates that new HSR line may lead to redistribution of spatial access depending on how well the new lines are connected to existing conven-tional rail and other transportation systems. Martinez and Giovani (2012) argue that the new HS2 likely attracts passengers from the routes currently served by the conventional rail, resulting declined accessibility to London and other major job centers for the com-munities along the conventional rail lines.

Early studies on the effects of European HSR network ant TEN reported an increased core-periphery imbalance across multiple countries [30,31]. While some cities benefited substantially by HSR generated polarization effects, others became further marginalized due to weak connection between the peripheral regions and the HSR cities.
Accordingly, the authors stressed the importance of improving regional transport infrastructures to integrate the HSR stations with the rest of the region for augmenting the agglomeration effects of HSR.

Prime locations with direct HSR connectivity do not automatically lead to economic gains. Chen and Hall (2012) in their case study of HSR in France and the UK show that, while HSR services strengthened the economic performance of regional capitals that are specialized in knowledge-based economy. The old industrial regions however did not all regenerate successfully despite their direct access to HSR. Vickerman (2018) reported the redistribution of economic activities resulting from HS1 in the UK [32]. Communities along the HS1 line gained considerable benefits while those located away HS1 endured decline. The observed HS1 impacts varied among different sectors; knowledge-based employment appeared to have significant gains attributable to HS1.

As HSR operations grow rapidly in China, empirical evidence on HSR impacts is also growing. Jiao, et al. (2014) analyzed the accessibility effects by HSR and other ground transportation and observed increased inequality in three spatial dimensions: between the Eastern, Central, and Western regions of China, between extra-large, large, and small to medium cities, and between cities distant from and nearby HSR stations [33]. The same study also reported enlarged internal disparities with the regions attributable to HSR. Zhu, et al (2015) echoed the concerns of Jiao, et al (2014) from their analysis of HSR's accessibility effects for the year of 2009 and 2013, which showed greater benefits enjoyed by the cities with direct HSR access than those without HSR, and the cities in the prosperous eastern China than those cities located in the hinterland [34]. Jiao et al. (2014) believed that the initial increase in SI resulting from the launch of HSR services would likely smooth out as HSR network expands over time. Chen and Vickerman (2017) found that intra-regional inequality increased in the Yangtze River Delta Area (YRDA) of China [35]. The study confirmed what Martinez and Giovani (2012) observed in Europe that lack of administrative collaboration and poor connectivity with HSR contributed to HSR associated intra-regional inequality.

Impact of transportation infrastructure on spatial inequality has been studies in multiple places of China. The research on intercity transportation network in Southeast Asia shows the general integrity among cities using Gini coefficient measuring the centrality rankings. Research on spatial disparity in China confirms the positive impact of HSR on regional economic convergence, especially in the east and north due to the high network density, while the decrease in accessibility disparity is the most significant in the Mid-Yangtze River region, southwest and south of China [36–38].

Regional inequality at the megaregional level under the influence of HSR deserves a focal attention but has not yet been studied adequately. This study aims to expand the knowledge base in the area.

Chapter 3. *Methods*

3.1. Study design and data sources

This study considers 39 megaregions that have been identified either by governmental agencies or academic researchers from three continents; they include 19 from China, 9 from Europe, and 11 from the United States. The analysis of SI contains two parts. Part 1 measures the SI of all 39 megaregions using Theil of employment and total economic output at county/NUTS3/prefecture levels. The European data were collected from Euro Stat at the year 2006 and 2016 including the population, employment and gross value added (GVA) at NUTS3 level. For the US dataset, the county-level total employment at 2006 and 2016 were collected from Business Dynamic Statistics (BDS), released in Fall 2020 through reference year 2018 reflects improvements and enhancements on several dimensions.

The datasets available for Theil index calculations were not consistent in years across the three continents. Accordingly, the study selected the year of 2016 as the benchmark year when the needed data for calculating Gini index was available for all 39 megaregions. Gini index measures for years before 2016 were also calculated for the purpose of assessing megaregional SI trends; they came in different time intervals between different continents based on the available data.

Table 1. Basic Information about the 39 megaregions of this study at the year of 2016

	Area km^2	**Population (million)**
US Megaregions (11)		
Cascadia	93,024	7.9
Florida	81,932	15.1
Front Range	159,297	7.7
Great Lakes	387,885	47.2
Gulf Coast	132,218	6.6
Northeast	190,550	55.2

Northern CA	105,763	13.3
Piedmont Atlantic	164,974	18.2
Southern CA	160,265	24.4
Sun Corridor	208,881	6.0
Texas Triangle	153,357	17.4
Europe Mega-City Region (9)		
South East England	29,184	19.0
The Randstad	8,757	8.6
Central Belgium	16,000	7.8
RhineRuhr	11,536	11.7
Rhine-Main	8,211	4.2
EMR Northern Switzerland	13,700	3.5
Paris Region	43,019	15.7
Greater Dublin	7,814	1.6
Northern Powerhouse	37,142	10.7
China City-Cluster Regions (19)		
Capital Zone (Jing-jin-ji)	182,320	70.2
Yangtz River Delta	200,056	117.7
Pearl River Delta	109,170	43.0
Shandong Gulf	73,192	39.7
Haixia West	225,471	85.0
Shanxi Middle	69,509	14.0
Zhongyuan	99,690	68.4
mid-Yangtze River	349,829	121.2
Guanzhong	72,958	23.9
Lanxi	73,269	9.9
Hubaoeyu	174,806	7.7
North Gulf	98,705	36.0
Chengyu	238,600	98.0

Qianzhou	74,924	13.3
Ningxia	13,156	2.6
Dianzhong	64,852	14.3
Tianshan North	190,612	2.2
Hachang	322,559	45.2
Liao Middle south	126,078	38.5

In the second part of close-up analysis, this study selects three individual megaregions. These are the Texas Triangle (USA), the Northern Powerhouse (NPh) (UK), and the Mid-Yangtze River City-Cluster Region (China). The selection of the three cases considered the observation that they share a similar spatial pattern of polycentric agglomeration. The Texas Triangle is spatially portrayed by three sets of anchor cities: Dal-las-Ft. Worth to the north, Houston to the southeast, and Austin-San Antonio to the southwest. Similarly, the Mid-Yangtze River City-Cluster Region (China) is characterized by the capital cities of three provinces, Wuhan, Changsha, and Nanchang in a triangle setting. The region has thus earned the nickname of the Central Triangle in reference to the Yangtze Triangle (or Yangtze Delta) of the greater Shanghai in eastern China and the Pearl River Triangle (or the Pearl River Delta) of the Guangzhou-Shenzhen-Zhuhai area in southern China. The NPh region consists of five approximately equally sized cities and does not have a single dominant city like London in the south of England. Its regional spatial pattern also displays a triangular shape, with Newcastle located on the north apex and other cities aligned with the base lateral.

Furthermore, NPh and the Texas Triangle have a similar population size between 10~20 million. When measured by highway travel times, the Texas Triangle of USA and the Central Triangle of China display similar dimension; the anchor cities of the triangle are all approximately three hours apart. The fact that all these three megaregions have either existing or proposed HSR operations makes them an interesting and comparable set of cases for this study.

The Texas Triangle is one of the eleven megaregions in the continental U.S. It is geo-graphically encompassed by the metropolitan areas of Houston, Austin/San Antonio, and Dallas/Fort Worth (Figure 4). The region is expected to grow, as its past suggests, by an additional 10 million people over the next 40 years. This vast growth presents many challenges. Demand for consumption will be enormous on land, water, and other natural resources. The region's population will become more diverse, with a large amount of international in-migration, posing challenging demands for employment, education, health care, and other services. A third challenge is mobility. National mobility studies show that all the metro areas in the Texas Triangle have been among the nation's top congested regions in the past two decades. The region's transportation infrastructure needs major enhancement to keep people and goods moving.

Currently there are two HSR lines proposed for the Texas Triangle: The eastern HSR line being developed by a private company, Texas Central, connects Dallas to Houston in a length of 234 miles. The western line is a portion of the Texas-DOT/Oklahoma-DOT jointly proposed rail corridor, which runs 850 miles from Edmond/Oklahoma City, Oklahoma to Brownsville at the Texas-Mexico border. The central section of the line connects Dallas-Ft. Worth to San Antonio through Austin in a length of 247 miles.

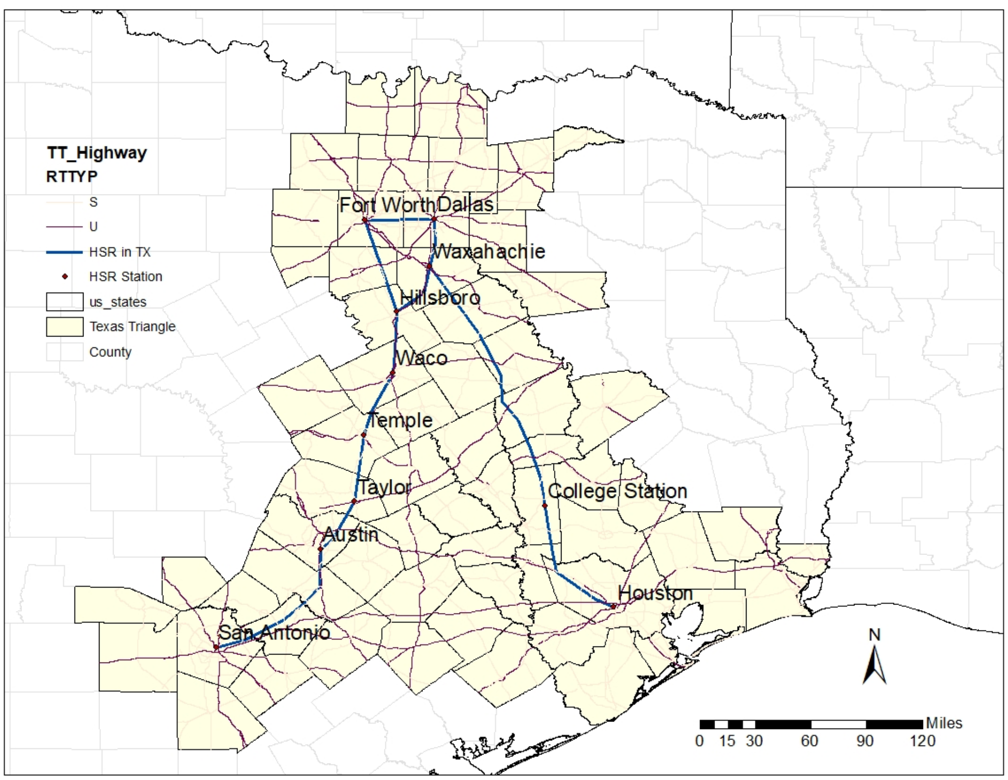


Figure 4. Texas Triangle Megaregion with Highway and Proposed HSR Network

The Northern Powerhouse (NPh) is an initiative aiming to strengthen the economic competitiveness of the North of England (Figure 5). NPh emerged as a response to the widening disparity between old industrial cities like Manchester, Leeds, Hull, Newcastle and Liverpool in northern England and the South of England centered around London. One of the three key NPh strategies is to boost high-speed rail links among NPh cities, fostering a competitive agglomeration comparable to the London region and other mega-city regions in Europe. High-Speed Two (HS2), a high-speed rail line currently un-der construction, connects London with Birmingham in Phase 1 and then to Manchester and Leeds in Phase 2. The proposed east-west rail in the North of England is often referred to as High-Speed Three (HS3) although the exact route has not been confirmed.

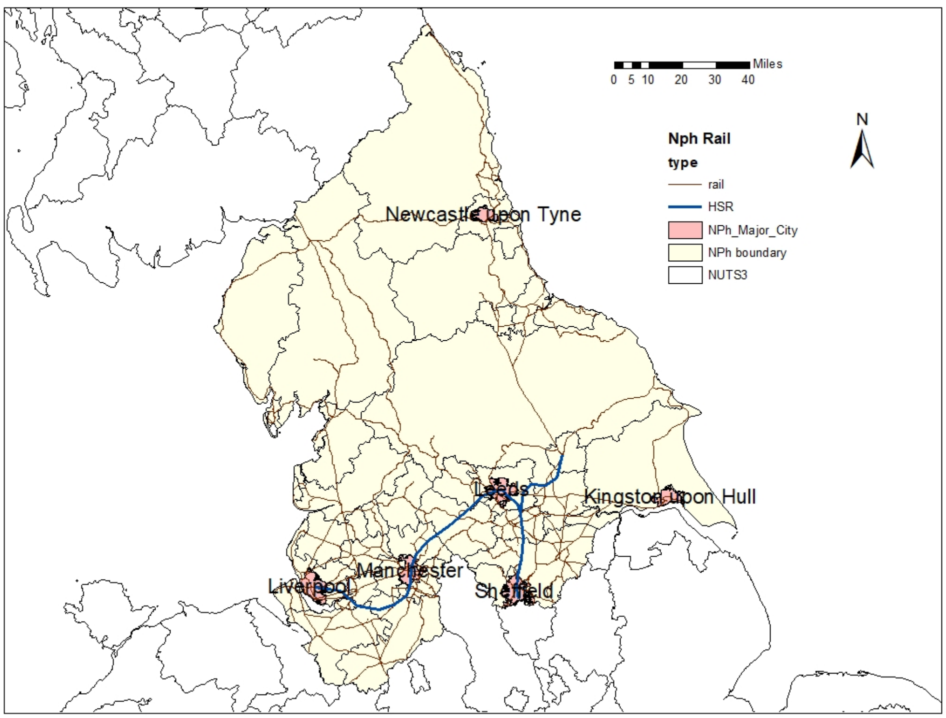


Figure 5. Northern Powerhouse with Traditional Railway and proposed HSR Network

The Mid-Yangtze River City-Cluster Region as the name stands is in the middle range of the Yangtze River (Figure 6). The region encompasses 185 counties/cities in 28 prefectures from three provinces in central China, Hubei, Hunan, and Jiangxi. Three provincial capital cities form an approximate equilateral triangle with each side measured 170~180 miles in airline distance. The region is known for offering rich resources in agricultural production, industrial and higher educational opportunities, multimodal transportation, and ecological resources. Wuhan, the capital city of Hubei Province, ranks No.5 nation-wide in terms of population. Wuhan, a city of more than 10 million inhabitants, was the northern terminus of China's first long-haul HSR line connecting Wuhan and Guangzhou, the provincial capital of Guangdong; the line began commercial service in December 2009 in a route length of over 600 miles. Wuhan's position as China's HSR hub became prominent in 2012 when the Beijing-Wuhan HSR route (750 miles) was completed.

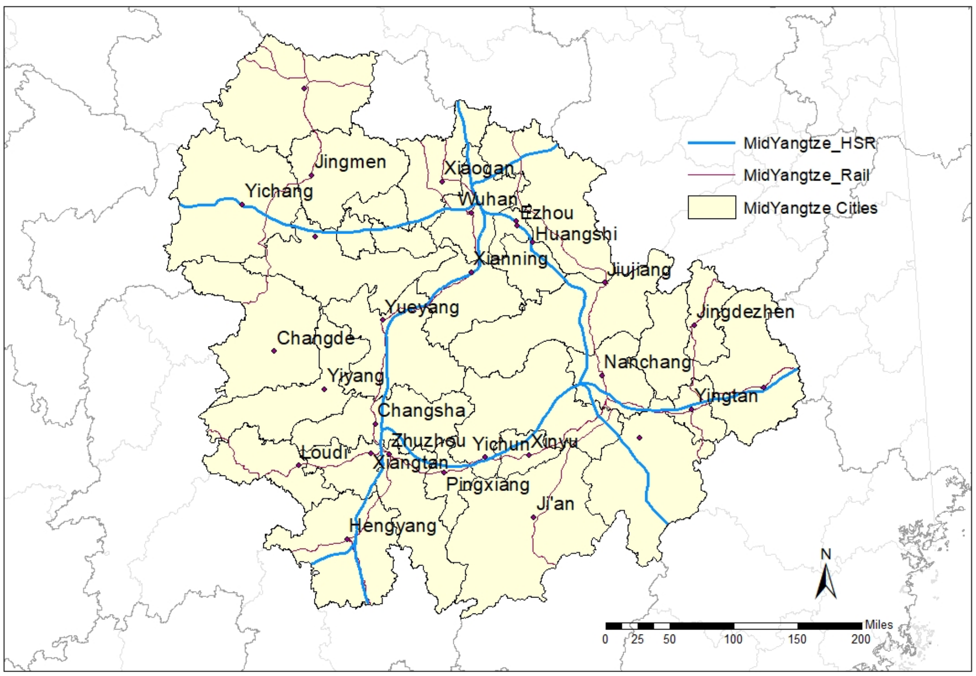


Figure 6. Mid-Yangtze River Megaregion with traditional railway and built HSR

3.2. Measures of Spatial Inequality

This study attempts to analyze megaregion SI in multiple dimensions. Specifically, the study uses Gini coefficient and Coefficient of Variance (CV) to measure the socioeconomic dimension of SI. To characterize the physical dimension of megaregion SI, the study applies the rank-size distribution to quantify the polycentricity of megaregions (See an application example by Hall and Pain, 2006). Furthermore, the study applies accessibility modeling to assess the role of HSR in shaping and modifying opportunity distribution in megaregions. Detailed methods of the above measures follow.

Weighted Gini coefficient

Gini Coefficient has been widely used to measure income or wealth distribution nationally. Traditional Gini coefficient measurement is based on frequency distribution by multiple income or wealth interval. The index of Gini Coefficient reveals how wealth within a country is distributed individually. Higher Gini Coefficient shows more inequality that more wealth is aggregated by the minority. Spatial Gini Coefficient is slightly different from traditional Gini coefficient, which measures inequality of regional wealth distribution. It applies geographic units as intervals and compares population proportion and wealth proportion within the region.

Spatial Gini Coefficient (geometric calculation):

$$G_m = \frac{\sum_{i=1}^{n}(\mathrm{P}_i(\sum_{i=1}^{n}E_i+\sum_{i=1}^{n}E_{i-1}))}{\sum_{i=1}^{n}P_i \cdot \sum_{i=1}^{n}E_i} \tag{1}$$

where G_m is the Gini Coefficient of megaregion m. for n geographic units (counties in US context, cities in Chinese context and NUTS3 region in European context) within megaregion m, E_i is the economic activity index, shown as income, GDP, and employment at unit i, P_i is the population at unit i. Geographic unit from 1 to n are ordered by the total economic index divided by the total population.

Coefficient of Variation (CV)

CV is a concept in probability and statistics, measuring the dispersion of a distribu-tion. In spatial inequality at megaregion level, CV describes the differentiation of eco-nomic resources (such as GDP, income and employment) per capita owned aggregated at county in US context, city in Chinese context and NUTS3 Region in European context.

$$CV_m = \frac{S.D.\frac{E_i}{P_i}}{\sum_{i=1}^{n}\frac{E_i}{P_i}/N} \tag{2}$$

After comparing these three methods, the study chooses to use Theil index for inequality measurements.

Measure of Polycentricity of Megaregions

This study derives a conferment from the Rank-Size Rule to quantify empirically the built-environmental characteristics of megaregions. Rank size rule is a model of urban hierarchies. It describes the rank and size relationship in the following form:

$$Rank = K \frac{1}{Size^{\alpha}} \tag{3}$$

Taking a log transformation gives a linear equation:

$$\text{Log (Rank)} = \text{Log(K)} - \alpha \text{ Log(Size)} \tag{4}$$

Where size is the population of a city and rank is the size rank of that city within the megaregion. K is the constant of the megaregion and α is estimated rank-size coefficient. The estimated coefficient α gives a measure of polycentricity of the megaregion. The larger value indicates the megaregion is more monocentric (Hall and Pain 2006).

Accessibility

The study applies a commonly used gravity model of accessibility measure. The model takes the following form:

$$A_i^Y = \sum_j \frac{E_j^Y}{(T_{ij}^Y)^{\alpha}} \tag{5}$$

where Ai represents the accessibility of county i; E_j measures destination attractive-ness at location j, and T is travel time by rail between origin i and destination j. Y denotes the year in which A is measured. The parameter α reflects travelers' sensitivity to time increase, which should be calibrated from travel behavior observed in local regions. Due to lack of the empirical data and for easy comparison across the cases, this study takes a value of 1, a parameter value generally acceptable for the study purposes (The World Bank 2014).

Destination attractiveness E_j may take different value input, which then suggests A being interpreted in different ways for specific analytical purposes. In this study E takes two types of data input, employment or employed people and GDP. For the accessibility calculated with employment, A serves as a measure of the geography of opportunities, capturing to some extend HSR related agglomeration effects (The World Bank 2014). For the accessibility calculated with GDP, A reads as a measure of market potential or the size of local/regional economic (Zheng and Khan 2013).

Chapter 4. Study Results

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

4.1. Inequality in 39 megaregions

This part compares the trend of regional inequality of 39 megaregions across three continents and eight countries between the year 2006 and 2016. The study conducts three different measurement and reported Theil Index as the most consistent one.

Table 2. Regional Inequality Change in 37 Megaregions

	Theil (GDP)		
	2006	2016	Change
US Megaregion			
Cascadia	0.076	0.099	30%
Florida	0.030	0.039	32%
Front Range	0.059	0.057	-4%
Great Lakes	0.051	0.051	-1%
Gulf Coast	0.143	0.084	-41%
Northeast	0.197	0.224	14%
Northern CA	0.071	0.136	91%
Piedmont Atlantic	0.139	0.132	-5%
Southern CA	0.019	0.026	34%
Sun Corridor	0.029	0.031	7%
Texas Triangle	0.072	0.075	4%
European MCR			
Central Belgium	0.064	0.058	-9%

*NorthernPH**	0.034	0.037	8%
Paris Region	-	0.159	-
Rhine-Main	0.133	0.103	-23%
RhineRuhr	0.080	0.067	-17%
*South East Eng**	0.016	0.014	-11%
The Randstad	0.053	0.047	-9%
China City Clusters			
Beibu Gulf	0.043	0.065	50%
Capital Zone	0.199	0.236	18%
Central of Dian	0.090	0.104	16%
Central Plains	0.140	0.165	18%
Central Qian	0.137	0.130	-5%
Central Shanxi	0.149	0.145	-3%
Central South of Liao	0.113	0.149	32%
Chengyu	0.110	0.097	-12%
Guanzhong Plains	0.109	0.079	-28%
Hachang	0.166	0.083	-50%
Hubaoeyu	0.157	0.066	-58%
Lanxi	0.197	0.211	7%
Mid-Yangtze River	0.146	0.182	24%
Ningxia	0.027	0.021	-22%
North Foot of Tianshan	0.237	0.045	-81%
Pearl River Delta	0.539	0.407	-24%
Shandong Peninsula	0.071	0.050	-29%
West Shore	0.165	0.139	-16%
Yangzte Delta River	0.183	0.132	-28%

Tables 2 report calculation results for the 37 megaregions. The calculations generate two categories of Theil Index for income- and employment-based measures, respectively. For each category, corresponding to two time points using income and employment data, respectively, for each megaregion. Two observations can be made from the results reported in Tables 2.

Chinese megaregions show the highest SI among the three continents. Notable, in 2016, the average Gini coefficient of the 19 megaregions' coefficients was reportedly 0.246. In the United States, the 11 megaregions average reported a Gini index value of 0.106. the average Gini for EU's fell in between at a value of 0.158. For employment-based Gini calculation, Chinese megaregions also produce the largest average value (0.269). High Gini for employment suggests more concentrated job distribution. European megaregions appear to have the most scattered distribution of jobs. The US megaregions fall in between. The high SI of Chinese megaregions relative to those in Europe and the United States may be explained by the current development conditions in China. Rapid economic growth and urbanization likely concentrate wealth and jobs in large, central cities while the overall income level remains low compared to those of European and US cities.

The study results presented above suggest the importance of examining SI from a megaregional perspective. Only looking at high-growth, high-income urban cores such as Shanghai, Beijing, and Shenzhen tend to mask the development slowness or economic hardship that many counties in the hinterland are experiencing.

The second observation from Tables 2 concerns with the SI trend indicated by the changes in Gini coefficients over time. In China, 14 of 19 city-clusters experienced a decline in income inequality from 2006 to 2016. The three-year data from 2013 to 2016 showed all but one mega-city regions in Europe showed improvement in income SI. In the United States, the picture shows a trend opposite to those in China and Europe: eight of the 11 megaregions saw rising income inequality from 2010 to 2016.

The Gini coefficients of employment show a rather different picture for the 37 megaregions than the income Gini figure. Overall, employment appeared to become more concentrated in megaregions over time. All the eight mega-city regions in Europe and all but one megaregion in the United States exhibit an upward trend of employment concentration. In China, the picture is rather mixed. From 2006 to 2016, ten of the 19 Chinese city-clusters saw more or no change in employment concentration, whereas the rest nine city-clusters displayed a rather spreading trend of employment among cities within the city-cluster region.

4.2. Polycentricity of Megaregions

Tables 3 report estimated rank-size coefficients as measures of megaregion polycen-tricity. For the US megaregions, changes in the rank-size coefficients from 2006 to 2016 appeared positive; the trend lines become steeper, indicating a trend towards a less pol-ycentric built environment. The magnitude of changes is rather small though. Changes in the European mega-city regions were also small, but more diverse than in the US megaregions. Rhine-Main, Paris Region, and the Randstad moved slightly toward less polycentric, whereas Central Belgium, RhineRuhr, and South East England decreased a bit in terms of their mono-centricity. Changes in China's city-cluster regions show a great deal of dynamics: those located in western China, for instance, Ningxia, Central Shanxi, Tianshan Northridge, and Chengyu saw biggest increase in their rank-size coefficients. It means that primary cities have increased their primacy in their respective regions, a phenomenon commonly seen in the early stage of fast urbanization.

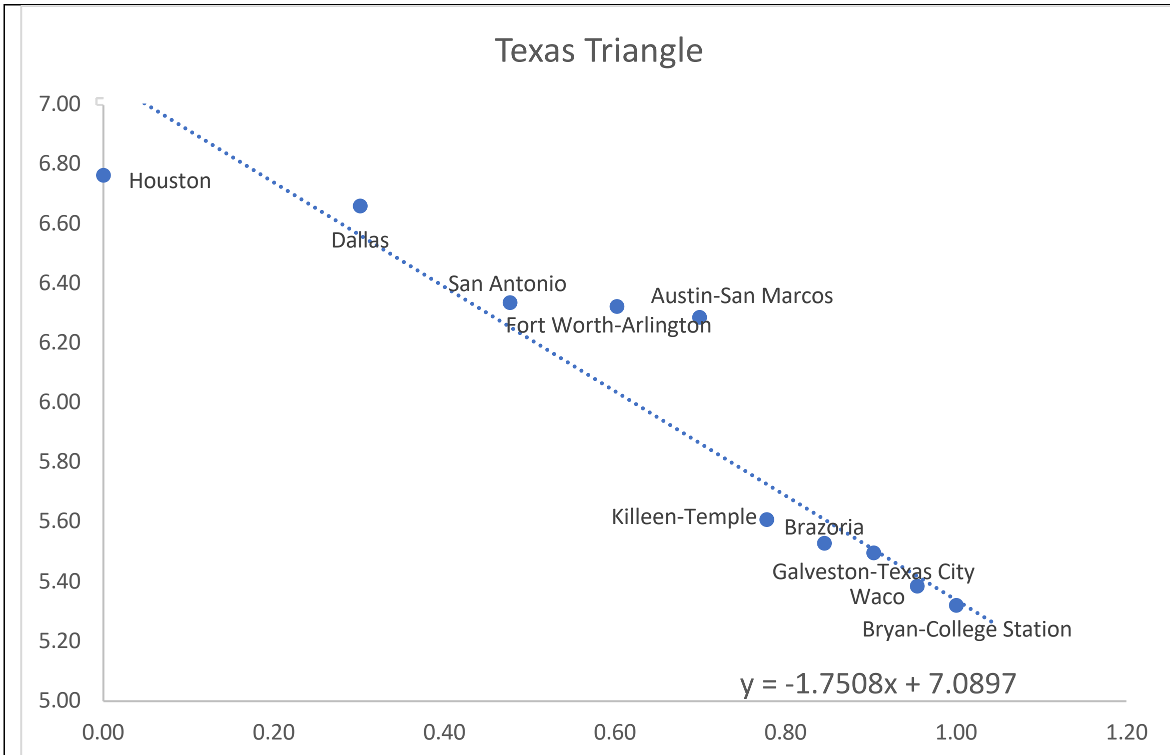
Table 3. Dynamic Changes of Polycentricity of 37 Megaregions

	Rank-Size Coefficient		
	2006	2016	Change
Southern CA	-1.525	-1.525	0.0%
Northern CA	-1.047	-1.059	1.1%
Piedmont Atlantic	-1.400	-1.427	1.9%
Great Lakes	-1.318	-1.325	0.5%
Sun Corridor	-2.489	-2.524	1.4%
Front Range	-1.400	-1.409	0.6%
Gulf Coast	-0.983	-0.992	0.9%
Texas Triangle	-1.735	-1.751	0.9%
Florida	-1.034	-1.036	0.2%
Cascadia	-1.518	-1.534	1.1%
Northeast	-1.187	-1.187	0.0%

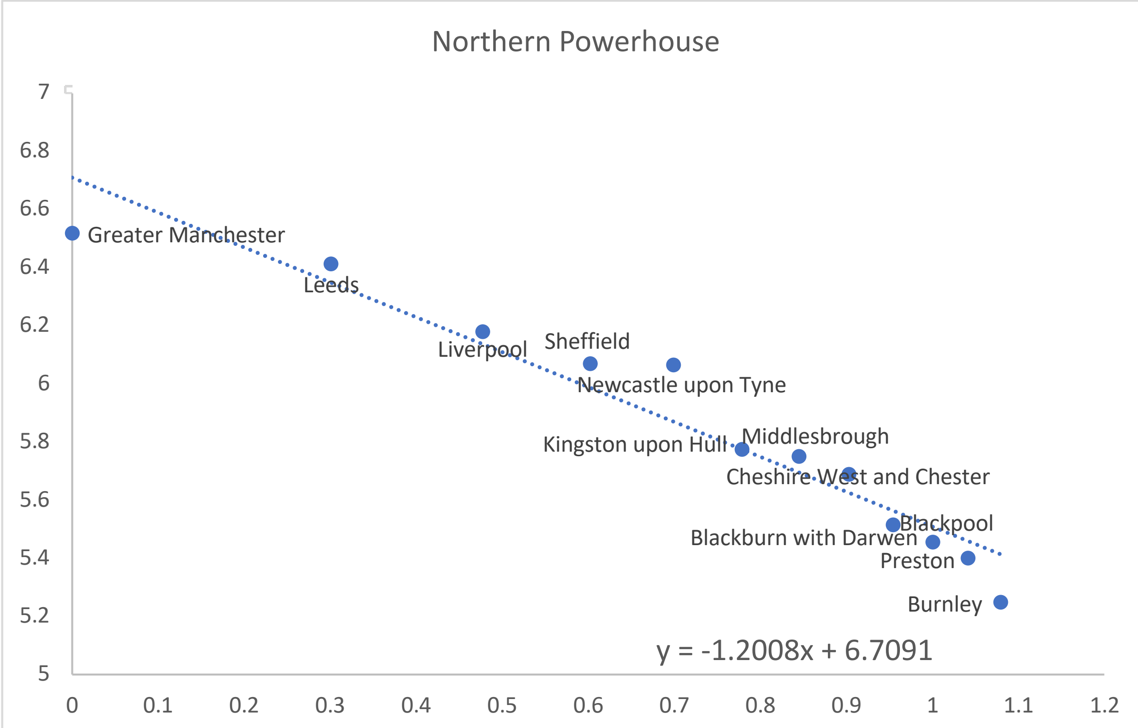
Average	-1.421	-1.434	0.9%
Standard deviation	0.481	0.492	0.021
European MCRs *[1]			
Central Belgium	-1.421	-1.219	-14%
Northern Powerhouse	-1.201	-1.201	0%
Northern Switzerland	-1.420	-1.474	4%
Rhine-Main	-1.143	-1.152	1%
RhineRuhr	-1.192	-1.185	-1%
Paris Region	-1.455	-1.485	2%
7%The Randstad	-1.241	-1.334	-27%
South East England	-1.651	-1.213	-14%
Average	-1.341	-1.283	-3%
Standard deviation	0.174	0.132	0.113
Chinese City Clusters			
Yangzte Delta River		-0.929	
Capital Zone		-1.468	
Pearl River Delta		-1.091	
Mid-Yangtze River		-0.733	
Chengyu		-1.087	
Hachang		-1.130	
West Shore		-0.862	
Central Plains		-1.317	
Guanzhong Plains		-1.394	
Lanxi		-1.132	
Hubaoeyu		-0.830	
Beibu Gulf		-0.984	
Shandong Peninsula		-0.730	

[1] Due to the data insufficiency, 7 out of 8 European MCRs do not have population data at FUA level, the closest time to 2006 with sufficient data is 2010.

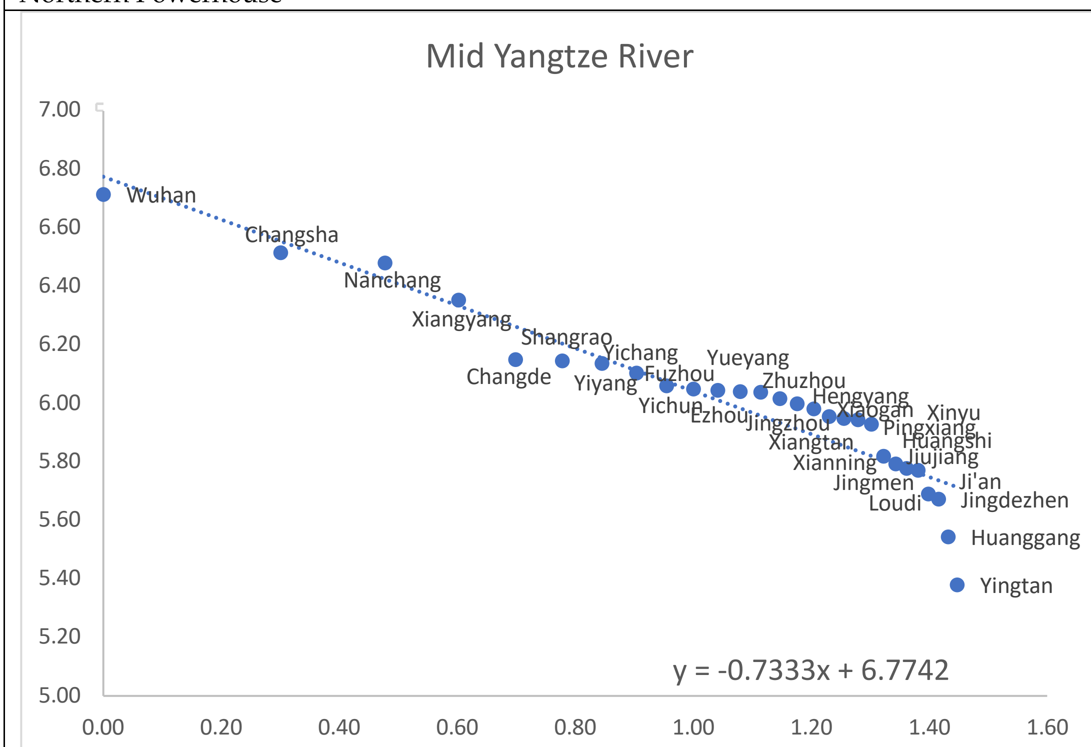
Central Qian		-0.538	
Ningxia		-1.361	
Central South of Liaoning		-0.869	
Central Shanxi		-1.590	
North Foot of Tianshan		-3.127	
Central of Dian			
Average	-0.761	-0.811	6.6%
Standard deviation	0.493	0.603	0.220



Texas Triangle



Northern Powerhouse



Mid-Yangtze River

Figure 7 Rank size distribution of Three megaregions in 2016

4.3. HSR Impact on Regional Inequality

HSR as an important indicator largely influences the mobility and accessibility among the regions. Better access will increase the exposure of job opportunities to some extent; however, the unbalanced exposure may cause inequality among the regions.

This part chooses three megaregions from UK, USA and China to test the accessibility inequality caused by built or proposed HSR lines. In MCR of Northern Powerhouse, there are two proposed HSR phases, HS2 as the main artery connecting London from the south all the way to the north of Manchester and Leeds in Northern Powerhouse. HS3 as a horizontal line contributes better connection from Liverpool to Leeds. In Texas Triangle megaregion, there were two proposed HSR lines, the Dallas-Houston (DAL-HOU) HSR and the Dallas-Austin-San Antonio HSR, connecting two edges of the triangle. In Mid-Yangtze River, the three anchor cities, Wuhan, Changsha and Nanchang has at least 2 HSR lines connecting the other two major metropolitans and cities along the way.

The accessibility measured in the three megaregions are based on the city/metropolitan level. In Texas Triangle, the before and after accessibility were calculated for 11 cities in the megaregion, all with a proposed HSR terminal/intermediate station. In the Mid- Yangtze River, it included 28 prefecture-level cities and in NPh, the accessibility was calculated for 6 major cities.

Tables 4 report the results of accessibility modeling for the three megaregions for scenarios with- vs. without-HSR. Overall, the Texas Triangle and the Northern Powerhouse all experience increase in accessibility associated with the proposed HSR services, although the magnitude of accessibility gains varies among individual cities and metropolitan areas. The picture for the Mid-Yangtze River city-cluster region looks a bit com-plex. Most of the region's cities enjoyed increase in both GDP- and employment-based accessibility. However, some have had losses for either GDP- or employment-based accessibility, or both.

To better illustrate changes in accessibility associated with HSR, Figures 8~13 map out the accessibility surfaces for the megaregions in the three continents.

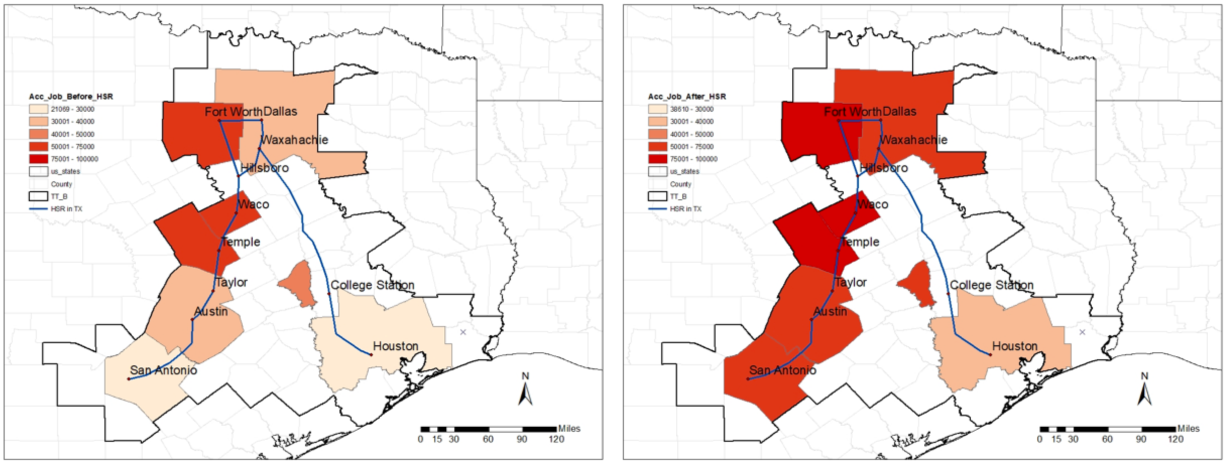


Figure 08. Job Accessibility without (left) vs. with (right) HSR in Texas Triangle

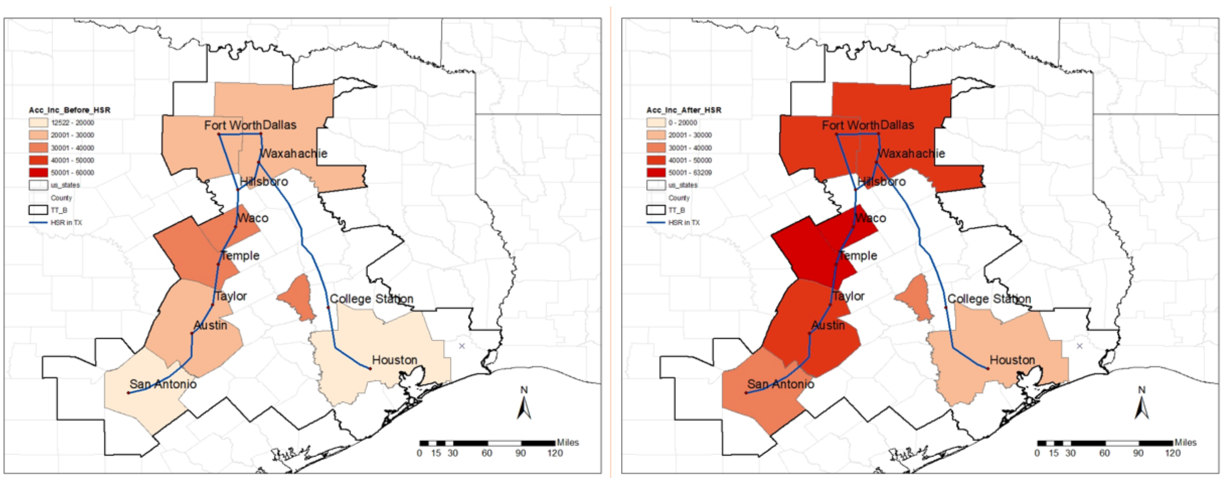


Figure 09. Income Accessibility without (left) vs. with (right) HSR in Texas Triangle

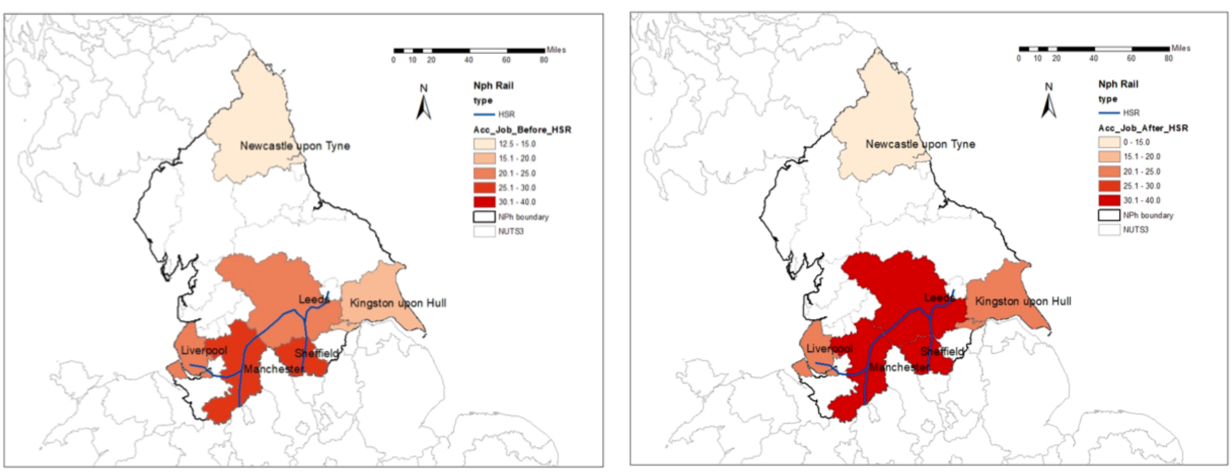


Figure 10. Job Accessibility without (left) vs. with (right) HSR in Northern Powerhouse

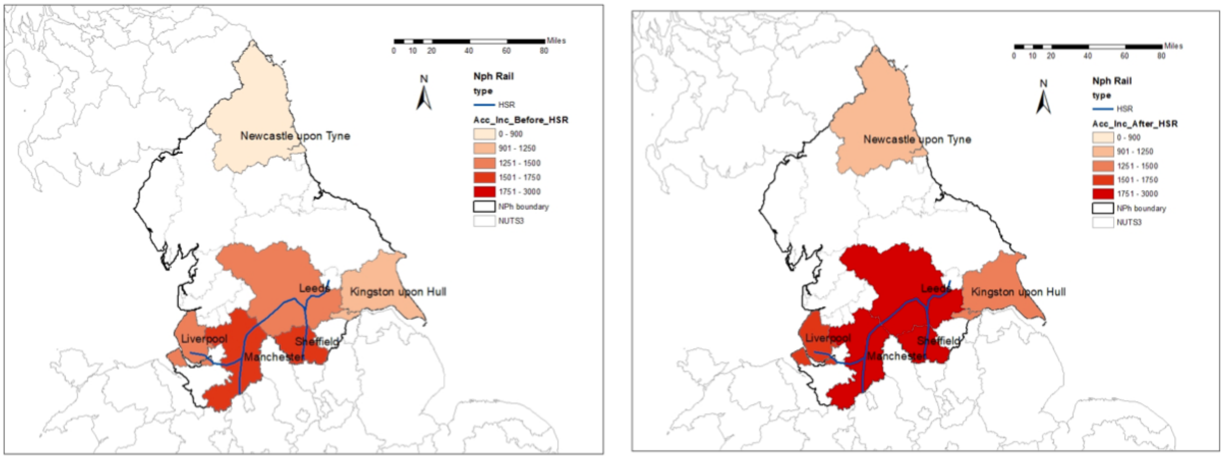


Figure 11. Income Accessibility without (left) vs. with (right) HSR in Northern Powerhouse

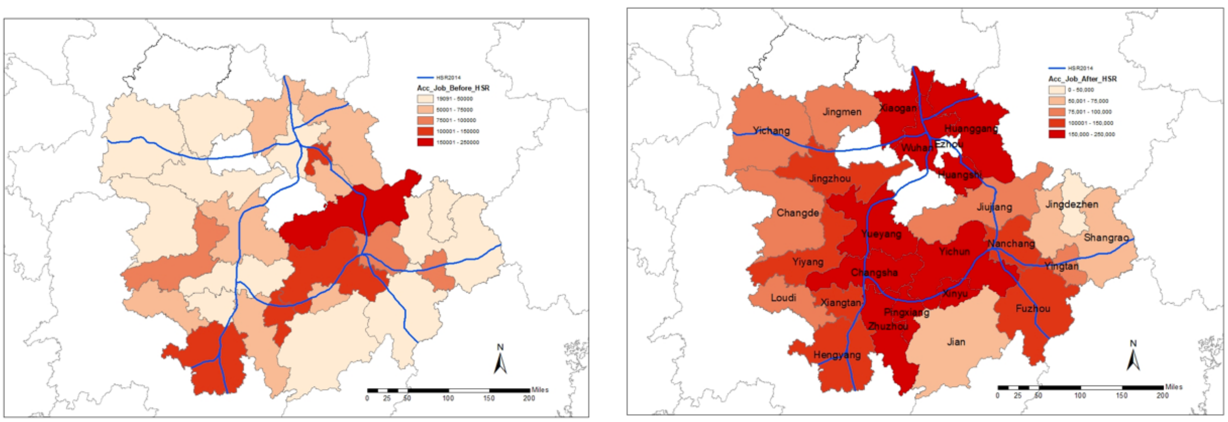


Figure 12. Job Accessibility without (left) vs. with (right) HSR in Mid-Yangtze River

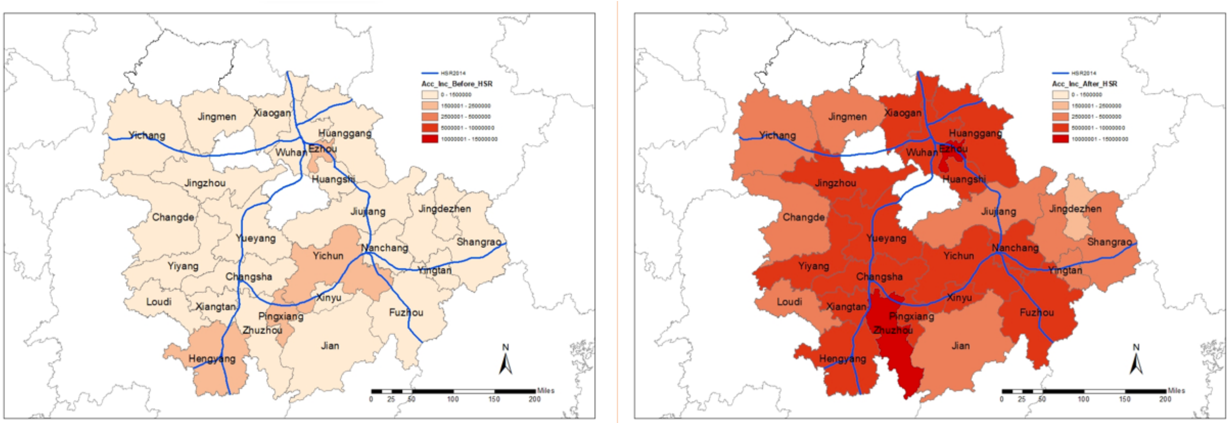


Figure 13. Income Accessibility without (left) vs. with (right) HSR in Mid-Yangtze River

4.4. SI changes measured by accessibility

Table 5 below reports changes in SI indicators before and after HSR in the Texas Triangle, the Northern Powerhouse, and the Mid-Yangtze River. Notably, both indicators of SI show increased SI associated with the proposed HSR services for the Texas Triangle. The Gini coefficients rise by 1.8% and 1.5% for GDP- and employment-based accessibility change, respectively. For the Northern Powerhouse case, Gini and CV display the oppo-site sign. The Gini measure indicates a decline in SI by about 13% decrease in coefficient values. In contrast, the CV estimates increase by about 35%. Explanations to the different signs of Gini and CV lie in the way these two indicators are constructed. Gini measures the distribution of accessibility against the ideal, proportional distribution of population, whereas CV measures the degree of dispersion of accessibility distribution, not necessarily proportional to the population distribution. Accordingly, the Gini and CV estimates for the Northern Powerhouse can be interpreted as that HSR potentially lead to a more evenly distributed wealth and employment opportunities among the population but in a higher degree of concentration across the region. The Gini and CV estimates for Mid-Yangtze River show that a higher level of income disparity was associated with HSR, yet employment opportunities became more evenly distributed with population. At the same time, both income and employment became more dispersed in the region after HSR operations.

Table 5 Measures of SI Changes by Accessibility with- vs. without HSR

	GDP-based			**Employment-Based**		
	No HSR	*With HSR*	*Change (%)*	*No HSR*	*With HSR*	*Change (%)*
Texas Triangle						
Gini	0.694	0.707	1.8%	0.696	0.707	1.5%
CV	0.259	0.311	19.9%	0.284	0.314	10.5%
The Northern Powerhouse						
Gini	0.248	0.216	-13.0%	0.243	0.211	-13.1%
CV	0.233	0.314	34.7%	0.235	0.318	35.4%
Mid-Yangtze River						
Gini	0.334	0.341	2.1%	0.368	0.3341	-9.2%

CV	0.468	0.415	-11.3%	0.527	0.3996	-24.2%

The varying results presented in the above tables and figures from analyzing three megaregion cases suggest two discussion points with respect to HSR's capacity to modify inequality:

The first is the importance of existing mobility condition. In European countries where there has been a long history of rail-based mobility services, HSR offers natural upgrades in mobility supply. The effects of incremental improvement from the rail up-grades would likely generate the effects on inequality commensurate to the magnitude of HSR-enabled mobility improvement. In the United States, personal mobility has been high (as indicated by high vehicle ownership at approximately 800 vehicles per thousand people and extensive flight services), the introduction of HSR is likely to offer mobility improvement modestly to particular market segments.

In China, personal mobility has been low relative to that in the developed economies. Introducing HSR has led to a major mobility elevation from relatively slow-moving transportation (e.g., walking, biking, bus, and animal driven transportation means) to fast moving, high-capacity trains. Such mobility elevation is significant particularly for in-ter-city, inter-province travel by a vast amount of business travelers, tourists, and migrant workers.
Perhaps more importantly, as the European Union did, China developed a national spatial strategy that integrates megaregion development with HSR investment. Wu, et al. (2016) observed that the multicore-network model of HSR would unlock the potential of megaregions to foster an unprecedented form of new urbanization.

Secondly, HSR's impacts magnify along with the scale of rail network extension. Polarization and corridor concentration dominate when HSR services occur in a few cities and regional corridors. As multiple corridors form a network, HSR's role to reduce spatial inequality will expand. In China and Europe, HSR or conventional rail have extensive networks. In contrast, HSR line is still non-existent in the United States. The Texas Triangle megaregion case looked at two potential HSR corridors. This network limitation likely generates negative impacts on SI, despite that the HSR services would improve access for the communities immediately served by the system.

Chapter 5. Conclusions

Amid growing concerns over the rising spatial inequality and the widespread interest in megaregions around the world, the report presents an effort to benchmark the conditions of spatial inequality in 38 world megaregions in the socioeconomic and physical dimensions measured by Gini and CV indices of GDP/income and employment and the rank-size coefficient of polycentricity. Furthermore, the study selected three megaregions, one from each continent, and assessed the role of HSR in reshaping SI of access to jobs and wealth. Two conclusions can be drawn from the study results.

First, megaregions offer a new spatial approach to address inequality issues. Megaregions across jurisdictional, or multi-national boundaries in the European case. A megaregional approach to SI helps uncover the disparity between fast growing, affluent core cities, and the by-passed, underperforming communities in the region. This emphasis on megaregional scale is not to diminish the importance of within-city inequality, but to voice that over focusing on the dominant cities likely masks the worsening SI in a broad spatial dimension.

Second, HSR elevates mobility by reducing travel times. Yet its role in reducing spatial inequality is contingent on the geographic coverage of HSR network, the pre-existing level of mobility of the served region, and the integration with other transportation systems to reach non-HSR locations. HSR offers fast and reliable travel advantageous over other travel means for a medium distance range of 100~500 miles. Its technological features make it inefficient economically and operationally to connect every part of the region. Polarization and corridor effects associated with HSR likely differentiate the places with direct HSR linkage and others without, widening SI especially in regions where HSR is newly introduced and limited in service coverage.

This report presents a first attempt to monitor spatial inequality conditions and trajectories in world megaregions and to analyze factors (HSR in this case) contributing to or modifying SI. The current work warrants further expansions in several directions. It is important to include megaregions or similar geographies from other parts of the world, for instance, the rest of Asia and countries in the Global South where mega-city regions exist or are emerging. In addition, the analysis should be expanded to consider other intervention policies and investments strategies aside from HSR. SI issue is complex and deserves in depth investigation with data in higher spatial resolutions and close examination on the variations among different social and economic dimensions on top of the spatial consideration. Only after gaining a better understanding of SI nature and causes can the policy makers respond with effective approaches to promote equality.

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